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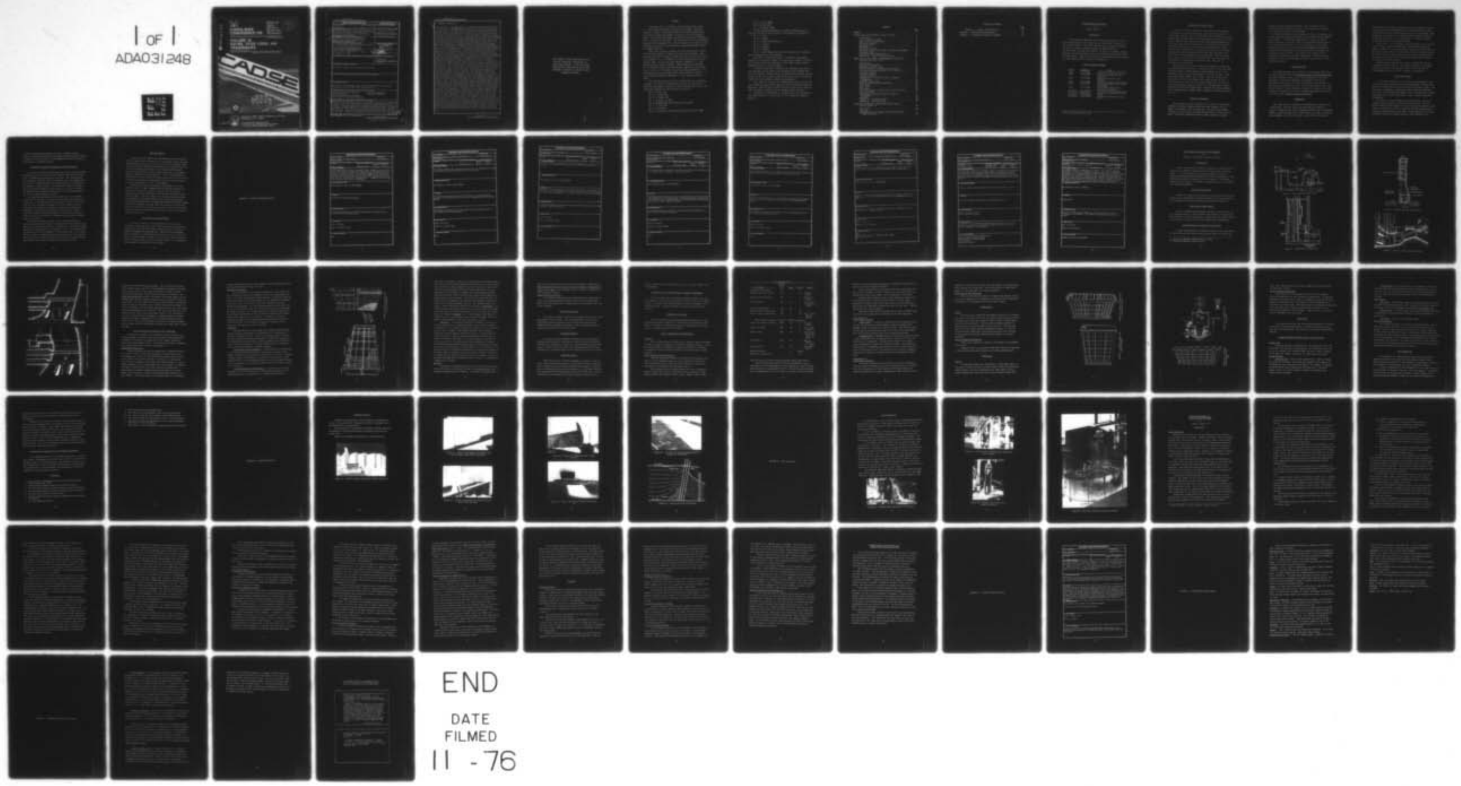

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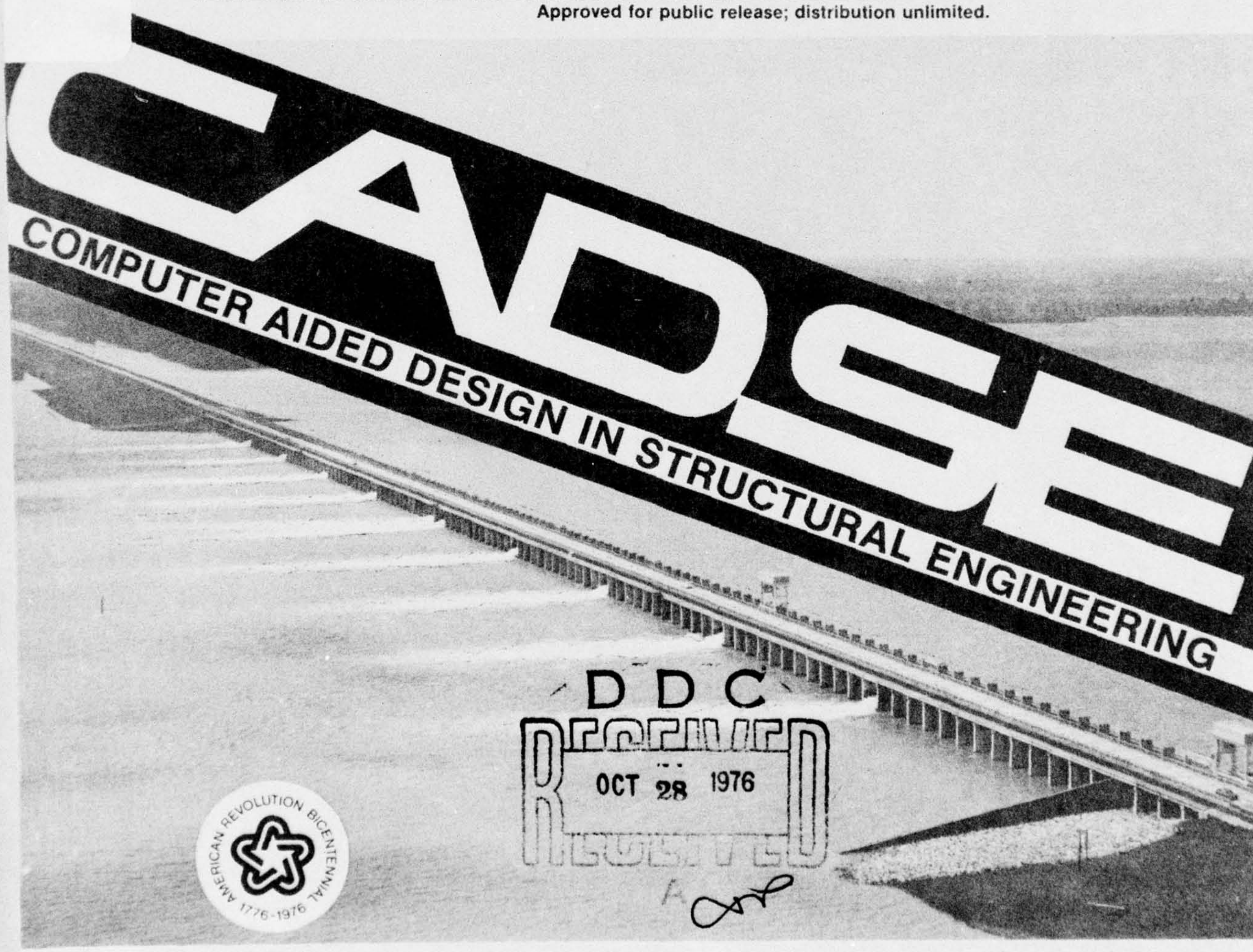
CORPS-WIDE CONFERENCE ON COMPUTER AIDED DESIGN IN STRUCTURAL ENGINEERING

22-26 September 1975

VOLUME VI
GATES, STOP LOGS, and TRASHRACKS

Edited by N. RADHAKRISHNAN



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Trashracks--Congresses

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TAINTER GATES FOR SPILLWAYS - The radial or tainter gate is the most common type of spillway crest gate used on dams. The Corps has constructed 800 in the last 15 years. Tainter gate advantages are simplicity, light weight, low hoist requirements, favorable hydraulics, and service and maintenance ease. Structural components for tainter gates are: skin plate assembly, end frames, trunnions, and anchorages. These are arc-welded from high strength, low alloy steel for the skin plate assembly and horizontal girders and structural carbon steel (A36)
(Continued)

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20. ABSTRACT (Continued)

for the end frames. Working stresses for tainter gate design should conform to EM 1110-1-2101. The basic allowable stress is 50% of the yield point of the steel being used. Gate dimensions are controlled by practical considerations, resulting in many 40- to 50-ft-wide tainter gates for flood control projects. Since the 1950's, prestressed concrete trunnion girders have been widely used, making these large gates practical. Several satisfactory programs for tainter gate design are available, but there is much duplication. These programs should be reviewed and tainter gate programs recommended for Corps-wide use. There are no programs available for designing prestressed concrete trunnion girders and anchorage systems; design programs should be developed for these items. This paper include abstracts of available programs for tainter gate design. WHEEL GATES, ROLLER GATES, & TRASHRACKS - Design requirements presented in this paper are a consolidation of criteria published in Corps engineering manuals. These criteria are supplemented by the documentation of field problems that need consideration for future designs. A simple trash structure is required at the upstream end of a reservoir outlet to keep trees and other large trash from entering the gate passages. It usually has horizontal and upright beams made of concrete, concrete encased I-beams, or concrete struts supporting steel pipes. Trashracks are critically important for hydropower projects to prevent turbine damage caused by trash penetration. Designers for this use must consider differential design head, trashrack bar spacing, head loss, vibration, and materials. No program for complete trashrack design exists. A Corps-wide program is needed. Gates control or regulate normal or emergency releases for the outlet works of a flood control project. Gate type choice is based on operating heads, safety, hydraulic efficiency, reliability, adaptability, and operation and maintenance costs. Roller, wheel, and slide gates are the types of vertical lift gates most commonly used by the Corps. Design procedures must allow for design head, discharge capacity, vibration, load selection, closing forces, corrosion protection, and the potential for gate catapulting. There are no published programs for a complete gate design. Gate computations are relatively brief, and District-level programming has not been economically feasible. A program for Corps-wide use would be practical. MITER GATES AND STOP LOGS - Miter gates for navigation locks fill and empty the lock chamber and provide walkways across the locks. Double-leaf miter gates, quickly opened and closed and low in maintenance costs, are usually chosen for moderate- and high-lift locks. Rigidity makes horizontally framed miter gates superior to vertically framed gates. In the mitered position, these gates form a three-hinged arch. Most miter gates are constructed by the Corps for navigation locks. A few are built by private industry to Corps requirements. The Mobile District computer program, "Miter Gate Design," has program design specifications in accordance with EM 1110-1-2101 and AISC allowable stresses. This program can save up to half the time required for manual computations. Other available programs are listed in the paper, along with useful requirements for new programs. Lock stop logs and spillway stop logs are used by the Corps for unwatering navigational locks and powerhouse intakes. They are not emergency closures. Computer programs can be easily adapted to the simple stop log design requirements. Several programs not specifically tailored for stop log design have been adapted for this use. These programs are listed in the paper. One program should be modified or written especially for truss-type stop logs and one for smaller logs made of plate girders. To minimize additional calculations, the output for stop log and miter gate programs should give directly the desired loads, thicknesses, and member sizes.

THE CONTENTS OF THIS REPORT ARE NOT TO BE USED FOR ADVERTISING, PUBLICATION, OR PROMOTIONAL PURPOSES. CITATION OF TRADE NAMES DOES NOT CONSTITUTE AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL PRODUCTS.

A

PREFACE

In December 1974, the Automatic Data Processing (ADP) Center, U. S. Army Engineer Waterways Experiment Station (WES), submitted a proposal to conduct a Corps-wide Conference on Computer-Aided Design in Structural Engineering (CADSE) to the Office, Chief of Engineers (OCE). OCE approved the proposal and efforts were started in February 1975 to conduct this Conference. The Conference was held in New Orleans, Louisiana, 22-26 September 1975, and was attended by 175 engineers from 48 Corps field offices, OCE, Construction Engineering Research Laboratory (CERL), and WES.

This volume contains the papers from Specialty Session B, State-of-the-Corps-Art Reports on Gates, Stop Logs, and Trashracks. When possible, abstracts of computer programs cited in the test are provided in an appendix. Mr. J. D. Gibson, Jr., was Session Chairman and presented a paper. He is a Structural Engineer, SAMEN-DT, U. S. Army Engineer District, Mobile, Alabama. Other papers were presented by Mr. K. O'Donnell, Chief, Structural Section, DAEN-CWE-D, OCE, Washington, D. C.; Mr. W. D. Churchill, Structural Engineer, MRDED-TS, U. S. Army Engineer Division, Missouri River, Omaha, Nebraska; and Mr. L. E. Sell, Mechanical Engineer, MROED-DB, U. S. Army Engineer District, Omaha.

The Conference was successful due to the efforts of a multitude of people. The roles they played were different but they were all directed toward making a concept on "instant dissemination" work. The Organizing Committee for the Conference consisted of:

COL G. H. Hilt, WES
Mr. F. R. Brown, WES
Mr. D. L. Neumann, WES
Mr. J. B. Cheek, Jr., WES
Dr. N. Radhakrishnan, WES--Conference Coordinator
Mr. W. A. Price, WES
Mr. G. S. Hyde, WES
Mr. D. R. Dressler, Lower Mississippi Valley Division (LMVD)

Mr. W. B. Dodd, LMNDE

Ms. E. Smith, LMNDE

Mr. L. H. Manson, LMNDE

An OCE Coordinating Committee also worked enthusiastically to ensure the success of the Conference. This Committee consisted of:

Mr. C. F. Corns

Mr. R. L. Delyea

Mr. R. F. Malm, OCE Coordinator

Mr. L. G. Guthrie

Mr. D. B. Baldwin

Mr. R. A. McMurrer

The U. S. Army Engineer District, New Orleans, did a remarkable job in playing host to the Conference.

There were 13 Division speakers, 25 moderators, two invited speakers, four technical speakers, and ten session chairmen, who shared the technical load of the Conference. Also, eight computer vendors showed their ware to the participants.

The editor would like to thank all the individuals who served on the committees and the speakers and the moderators for sharing their time and thoughts. Without them the Conference would not have been the success it was. Mr. Dressler, LMVD, and Mr. Price, WES, are specially thanked for their technical guidance and assistance.

This report was edited by Dr. Radhakrishnan, Research Civil Engineer, Computer Analysis Branch (CAB), and Special Technical Assistant, ADP Center, under the direct supervision of Mr. Cheek, Chief, CAB, and under the general supervision of Mr. Neumann, Chief, ADP Center.

The Director of WES during the Conference and the preparation of this report was COL G. H. Hilt, CE. Mr. F. R. Brown was Technical Director.

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TAINTER GATES FOR SPILLWAYS

by

Keith O'Donnell*

Introduction

This discussion summarizes the "state-of-the-Corps-art" for the structural design of tainter gates and the application of computers to aid in these designs. Most of the material on the structural design of the gates is from the guidance presented in Engineer Manual EM 1110-2-2702 and Guide Specification CE 1503. Ten separate computer programs have been developed in the Corps covering the structural design of tainter gates. Abstracts for eight of these programs with descriptions of their capabilities are presented in Appendix A.

List of Computer Programs

Office	Program No.	Title
Tulsa	713-G1-M001	Tainter Gate Loads and Reactions
Tulsa	713-G1-M002	Two-Girder Tainter Gate Rib Analysis
Tulsa	713-G1-M003	Tainter Gate Exterior Rib Analysis
Tulsa	713-G1-M004	Tainter Gate Rigid Frame Analysis
Tulsa	713-G1-M007	Four-Girder Tainter Gate Interim Rib Analysis
Tulsa	713-G1-M008	Three-Girder Tainter Gate Interior Rib Analysis
Galveston	713-F3-M3510	Skin Plate System Design/Analysis
Kansas City	713-R3-C124	Tainter Gate Analysis and Design
St. Louis	713-G1-A3110	G-Frame
Huntington	713-K2-H1105	Design of Three-Girder Tainter Gate

* Chief, Structural Section, OCE.

Application of Tainter Gates

The radial or tainter gate is the most common type of spillway crest gate used today on dam projects. Because of the simplicity, light weight, and the low hoist requirements of the tainter gate, economy has been the basic reason for its increased usage for the past many years. However, this type of gate offers additional advantages over other gate types, such as permitting a very favorable design from the standpoint of hydraulics, ease of service, and maintenance. While there are other applications for tainter gates, such as lock filling and emptying valves and upper gates for lock and sluice gates, this discussion is limited primarily to spillway gates. Special tainter gates, such as the moment-resisting shell types, have also been used, particularly for long spans on navigation dams. These are not included in this discussion.

During the past 15 years the Corps has designed and constructed about 800 spillway tainter gates. These gates cover a very wide range of head and span. Maximum hydraulic heads designed for are in the northwest where gates have been designed for 61 feet of head. These gates have usually spanned about 50 feet. Gates on the Ohio River have spans up to 110 feet combined with a head of about 42 feet. A variety of tainter gate types have been developed, but the original cost and maintenance charges can be held to a minimum only by careful selection of type and by sound design. Emphasis is placed on simplicity of framing using a minimum number of members of fairly heavy cross section.

Structural Components

The principal structural components of the gate are the skinplate assembly, the members supporting the skin plate assembly, the end frames, the trunnions, and the anchorages. The skin plate assembly consists of the skin plate, stiffened and supported by curved vertical beams. The members supporting the skin plate assembly are girders

spanning the gate opening horizontally. The end frames carry the reactions from the horizontal girders to the trunnions and the trunnions transmit the load to the anchorages.

All shop fabrication on tainter gates is done by arc welding. Any stress relieving is generally limited to the trunnion hub and trunnion yoke assembly. The structural components of the gate are made of either structural carbon steel (A36) or high strength low alloy steel. It has generally been found that it is economical to use the high strength low alloy steel for the skin plate assembly and horizontal girders while column stability may dictate the use of structural carbon steel for the end frames. An economic study should be made considering various steel strength combinations. Reduction in gate weight due to use of high strength steel will allow the use of lower capacity gate hoist.

Working Stresses

The working stresses for the design of tainter gates should be in accordance with EM 1110-1-2101, Working Stresses for Structural Design. The basic allowable stress is 50% of the yield point of the steel being used. For Group II loadings, the allowable stress may be increased 33-1/3%. Where ice load is applicable, 5 kips per foot of gate width has generally been used. If ice loading occurs over a long period of time, it may be desired to consider it a Group I load. Wave pressures on tainter gates can be determined approximately by methods in EM 1110-2-1603, Hydraulic Design of Spillways.

Dimensions

Many items must be considered in establishing the dimensions for a tainter gate. The pier spacing and gate width are limited by practical considerations, such as maximum desirable length of monoliths, length of spillway bridge spans, drift hazards, and loads on trunnions and anchorages. Generally, the width of gate will be the width of

monolith less the thickness of the pier, since more than one contraction joint per gate is undesirable. This is one reason why so many tainter gates for flood control projects are 40 to 50 feet wide. The height and overall width of the spillway opening should be selected to minimize the overall cost of the spillway. A study of various height-to-width ratios is usually required.

Within limits, it is desirable to use high gates rather than low ones to obtain a given discharge since a more economical spillway results. However, as the gate height is increased, a longer radius of gate will require longer piers for proper location of trunnion girder. The radius of gate is also affected by the vertical distance between the bottom of the gate in the lowered position and the low steel of the gate in its raised position.

Bridge clearance may also be a factor in determining the gate radius and trunnion location. The minimum thickness of all members carrying calculated stress should be 3/8 in. except for webs of bracing members in which 5/16-in. thickness is permissible.

Skin Plate Assembly

It is usually economical to use two or more thicknesses of skinplate due to the constant span under varying loading. The skin plate should be thickened in the zone of contact with the hoist cables. The skin plate is designed as a continuous member spanning horizontally across the vertical supporting members (ribs). The skin plate supporting members are vertical curved beams, or ribs, without horizontal intercostals.

The ribs are usually standard or wide flange tees, but may be standard rolled sections, or can be built up of plates. The tee sections with the stems welded to the skin plate are preferred to wide flange or I-sections in order to avoid the corrosion problem under a contacting flange welded at both edges. Wider spacing of ribs may be preferred, even with a slight increase in steel quantities, to

facilitate welding and maintenance painting. Combined biaxial stresses resulting from the skin plate spanning horizontally and acting as flanges of the ribs should be investigated by using the distortion energy theory of combined stresses.

Horizontal Girders, End Frames, and Trunnion Assembly

A majority of spillway tainter gates have three horizontal girders. However, gates less than about 25 feet high may require only two girders; the higher gates require more than three. The girders may be rolled sections for small gates, but generally they are weldments made up of plates. AASHTO specifications should generally be followed in the design of the gate girders. The girders can usually be spaced so that the cantilever moment with wave action is less than 1.33 times the maximum negative moment without wave action, permitting design of the ribs for a normal moment condition.

In considering the design of the tainter gate itself, maximum economy will be obtained by inclining the end frames to intersect the center line of the girders at about one-fifth of the gate width from each end. The side thrust component of the gate trunnion reaction resulting from an inclined end frame is resisted by designing the anchorage to transmit the thrust directly into the pier. While inclined end frames are usually desirable for flood control projects, their use may not be feasible for navigation projects where floating debris is a problem.

The trunnion assembly consists of (a) a trunnion hub with a bronze bushing and heavy flanges to transmit the reaction from the end frame, (b) a trunnion yoke, and (c) a trunnion pin. The hub-and-flange assembly is usually of forged or structural steel. The trunnion yokes are usually cast steel or weldments of structural steel. The trunnion pins are usually of forged steel and where required for corrosion protection the pin is either protected by 1/8 inch of corrosion resisting weld material or by using a corrosion resisting steel sleeve.

Anchorage System

Prior to the late 1950's, the anchorage system most frequently used for tainter gates consisted of a steel girder, usually box type, cantilevered at each face of the pier to receive the trunnion loads. For this system the loads from the trunnion are transmitted into the pier by an anchorage consisting of two standard rolled beams or built-up sections welded to the trunnion girder and to an embedded girder or grillage at the upstream end. To allow free movement or deformation of the tie beams and prevent tension in the pier concrete, the beams are unbounded or mechanically isolated from the concrete for the entire length by 1/2 in. of cork mastic.

Prestressing concrete had advanced considerably by the late 1950's in the U. S. and it appeared that the natural solution is to prestress the anchorage system of a tainter gate into the pier. Designs of prestressed anchorages involving about 800 tainter gates have been used. Since the concept of prestressed anchorage systems was introduced, it has been possible to use larger tainter gates. In these the trunnion load on a single pier exceeds six million pounds, with far less embedded anchorage metal than previously required and without a substantial increase in pier size. The use of prestressed concrete trunnion girders has proven economical and has been adopted throughout the Corps.

Conclusions and Recommendations

It was the consensus of the representatives attending this speciality session that the various existing tainter gate programs be reviewed by a few individuals before making a decision on which programs to recommend for Corps-wide use. While all of the programs appear satisfactory, considerable duplication now exists. Since there are no available computer programs for the design of the prestressed concrete trunnion girders and the anchorage system, it is recommended that programs be developed for these designs.

Appendix A: Computer Program Abstracts

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Tainter Gate Loads and Reactions			713-G1-M0010
PREPARING AGENCY			
U. S. Army Engineer District, Tulsa			
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM — PHASE	STAGE
Dean B. Englund	October 1968	Init.	Op.

A. PURPOSE OF PROGRAM

This program computes the sill location and slope, the dead load sill reactions, the dead load trunnion reactions, the wave loads, the wave load trunnion reactions, the trunnion reactions due to impact loading, and the trunnion reactions due to hydrostatic load. The cable pull, angle of pull, the location and length of contact, and reactions due to cable pull (including friction) are given for both an overwound and underwound hoist. A summation of the trunnion reactions for various cases is also produced.

B. PROGRAM SPECIFICATIONS

This program is written in CARD FORTRAN.

C. METHODS

All forces are statically determinate.

D. EQUIPMENT DETAILS

The equipment required is the GE 225 central processor (8K memory) with a card reader and a high speed printer.

E. INPUT-OUTPUT

Input is by cards.

Output is on printer paper.

F. ADDITIONAL REMARKS

None.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Two-Girder Tainter Gate Interior Rib Analysis			713-G1-M0020
PREPARING AGENCY			
U. S. Army Engineer District, Tulsa			
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
Dean B. Englund	October 1968	Init	Op.

A. PURPOSE OF PROGRAM

This program computes, for a two-girder tainter gate, the optimum girder spacing and the moments, shears, and reactions of the interior ribs.

B. PROGRAM SPECIFICATIONS

The program is written in CARD FORTRAN.

C. METHODS

The rib with two supports is statically determinate. The computed girder spacing is that spacing which will produce equal maximum positive and negative moments.

D. EQUIPMENT DETAILS

The equipment required is the GE 225 central processor (8K memory) with a card reader and a high speed printer.

E. INPUT-OUTPUT

Input is by cards.

Output is on printer paper.

F. ADDITIONAL REMARKS

None.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
Tainter Gate Exterior Rib Analysis	713-G1-M0030

PREPARING AGENCY

U. S. Army Engineer District, Tulsa

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
Dean B. Englund	October 1968	Init.	Op.

A. PURPOSE OF PROGRAM

This program computes the moments, shears, and reactions for the exterior rib of a 2-, 3-, or 4-girder tainter gate under normal and stall torque cable tension.

B. PROGRAM SPECIFICATIONS

This program is written in CARD FORTRAN.

C. METHODS

Slope deflection equations are used to compute the moments over the supports for the 3- and 4-girder analysis. Positive moments, shears, and reactions are found from free body diagrams. The 2-girder analysis is statically determinate

D. EQUIPMENT DETAILS

The equipment required is the GE 225 central processor (8K storage) with a card reader and a high speed printer.

E. INPUT-OUTPUT

Input is by cards.

Output is on printer paper.

F. ADDITIONAL REMARKS

None.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Tainter Gate Rigid Frame Analysis			713-G1-M0040

PREPARING AGENCY

U. S. Army Engineer District, Tulsa

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
Dean B. Englund	October 1968	Init.	Op.

A. PURPOSE OF PROGRAM

This program computes the moments, reactions, axial loads, and unit stresses for a tainter gate frame comprised of 1 girder and 2 struts.

B. PROGRAM SPECIFICATIONS

This program is written in CARD FORTRAN.

C. METHODS

The moments, reactions, and axial forces are computed by the use of slope deflection equations and free body diagrams. The unit stresses are computed according to EM 1110-1-2101, "Working Stresses for Structural Design" and the Sixth Edition of the "Steel Construction Manual."

D. EQUIPMENT DETAILS

The equipment required is the GE 225 central processor (8K storage) with a card reader and a high speed printer.

E. INPUT-OUTPUT

Input is by cards.

Output is on printer paper.

F. ADDITIONAL REMARKS

None.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Four-Girder Tainter Gate Interior Rib Analysis			713-G1-M0070
PREPARING AGENCY			
U. S. Army Engineer District, Tulsa			
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
Dean B. Englund	October 1968	Init.	Op.

A. PURPOSE OF PROGRAM

This program computes, for a four-girder tainter gate, the optimum girder spacing and the moments, shears, and reactions of the interior ribs.

B. PROGRAM SPECIFICATIONS

The program is written in CARD FORTRAN.

C. METHODS

The rib is analyzed by the use of slope deflection equations. The computed girder spacing is that spacing which will produce equal maximum negative moments.

D. EQUIPMENT DETAILS

The equipment required is the GE 225 central processor (8K memory) with a card reader and a high speed printer.

E. INPUT-OUTPUT

Input is by cards.

Output is on printer paper.

F. ADDITIONAL REMARKS

None.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Three-Girder Tainter Gate Interior Rib Analysis			713-G1-M0080
PREPARING AGENCY			
U. S. Army Engineer District, Tulsa			
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
Dean B. Englund	October 1968	Init.	Op.

A. PURPOSE OF PROGRAM

This program computes for a three-girder tainter gate, the optimum girder spacing and the moments, shears, and reactions of the interior ribs.

B. PROGRAM SPECIFICATIONS

This program is written in CARD FORTRAN.

C. METHODS

The rib is analyzed by the use of slope deflection equations. The computed girder spacing is that spacing which will produce equal maximum negative moments.

D. EQUIPMENT DETAILS

The equipment required is the GE 225 central processor (8K memory) with a card reader and a high speed printer.

E. INPUT-OUTPUT

Input is by cards.

Output is on printer paper.

F. ADDITIONAL REMARKS

None

Main = 02742, Sub Fixed = 00340, Sub Bend = 00235
Sub Record = 01255

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
SKNPL - Skin Plate System Design/Analysis	713-F3-M3510

PREPARING AGENCY
U. S. Army Engineer District, Galveston, P. O. Box 1229, Galveston, TX 77550

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
William A. Price Structural Engineer	December 1969 Mod Dec 1974	MOD	OPER

A. PURPOSE OF PROGRAM

Analysis and/or design of an orthogonal, planar steel skin plate and composite tee rib system. (Ribs may be any steel shape or the program will select a structural tee from an internal table of 26 WT's and ST's for minimum cost. Costs are computed for comparative designs, steel and welding costs included. Combined stress is checked in accordance with EM 1110-2-2702, for 2-D (planar) action.)

B. PROGRAM SPECIFICATIONS

Written in G-600 time-sharing FORTRAN for the G-635 time-sharing computer.

C. METHODS

First-order working stress theory, no plate diaphragm action.

D. EQUIPMENT DETAILS

G-635 time-sharing computer
Remote low-speed terminal

E. INPUT-OUTPUT

Interactive I/O with numerous programmed error checks and restart options. A chart of user control, describing the options at each decision point, is shown in paragraph 6 of the writeup.

F. ADDITIONAL REMARKS

Copies of the writeup are available from:
Engineer Computer Program Library
USAE Waterways Experiment Station
P. O. Box 631
Vicksburg, MS 39180

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM		PROGRAM NO.
Tainter Gate Analysis and Design		713-R3-C124

PREPARING AGENCY

U. S. Army Engineer District, Kansas City

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
Marion M. Harter, Ervell A. Staab, Roy D. Reed	January 1968	Init.	Rep.

A. PURPOSE OF PROGRAM

This program consists of subprograms as follows: (1) Interior Rib Design - determines the location of the girders supporting the ribs, the rib shears and moments, and some gate geometry; (2) Exterior Rib Design - determines shears and moments for the exterior ribs due to load from lifting cable; (3) Rigid frame and stress analysis - determines forces, stresses, and deflections in a frame consisting of the girder supporting the ribs and two struts transmitting the loads to the trunnion; (4) Tainter Gate reactions - determines trunnion reactions at various gate openings when supported equally with cables.

B. PROGRAM SPECIFICATIONS

The program is written in FORTRAN II.

C. METHODS

EM 1110-2-2702

D. EQUIPMENT DETAILS

The data processing system consists of a 40K Central Processor with the following on-line equipment: card reader, 4-reel magnetic tape unit, and printer.

E. INPUT-OUTPUT

Input is on cards.

Output is by the printer.

F. ADDITIONAL REMARKS

Program write-up is not available.

WHEEL GATES, ROLLER GATES, AND TRASHRACKS

by

William D. Churchill* and Lloyd E. Sell**

Introduction

In this session we will present a composite of considerations to be made in the design of trashracks and of roller, wheel, and slide gates. It is a consolidation of criteria published in Corps of Engineers engineering manuals supplemented by the documentation of field problems that should be considered in future designs. The ultimate purpose of this session is to relate the design process to the potential for computer programming.

Reservoir Outlet Works

Profiles of typical outlet works for flood control projects showing the usual configuration of trash structures, stop logs (bulkheads), and of emergency and service gates are illustrated in Figures 1-3.

Hydroelectric Power Project

Typical hydropower water passages are shown in Figures 4-6. Figure 4 shows the Harry S. Truman inclined pump turbine in the pump-back power facility now under construction. Figures 5-6 show similar intakes for the Harry S. Truman and the Clarence Cannon Dams, respectively.

Trash Structures for Reservoir Outlet Works

A simple trash structure is normally required at the upstream end to catch trees and other large trash which may reach the entrance and

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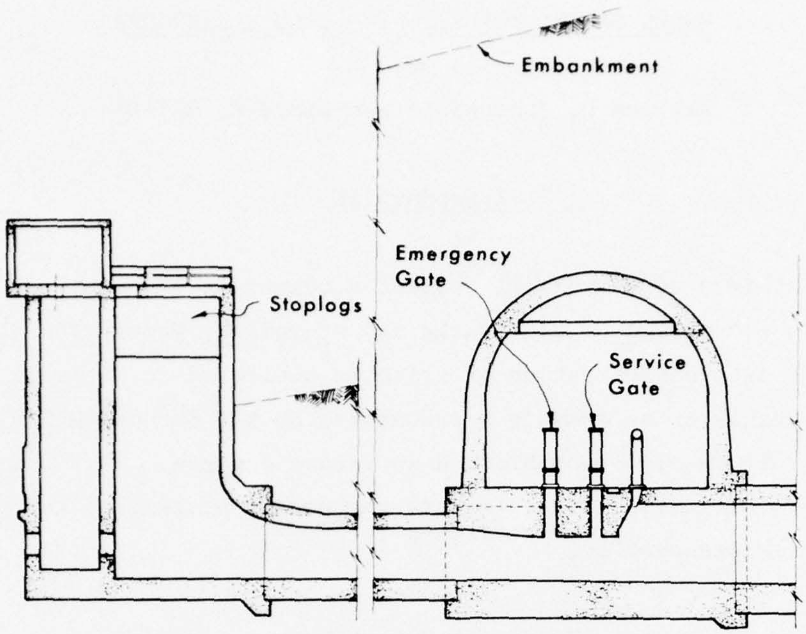

Figure 1. Bear Creek Dam outlet works

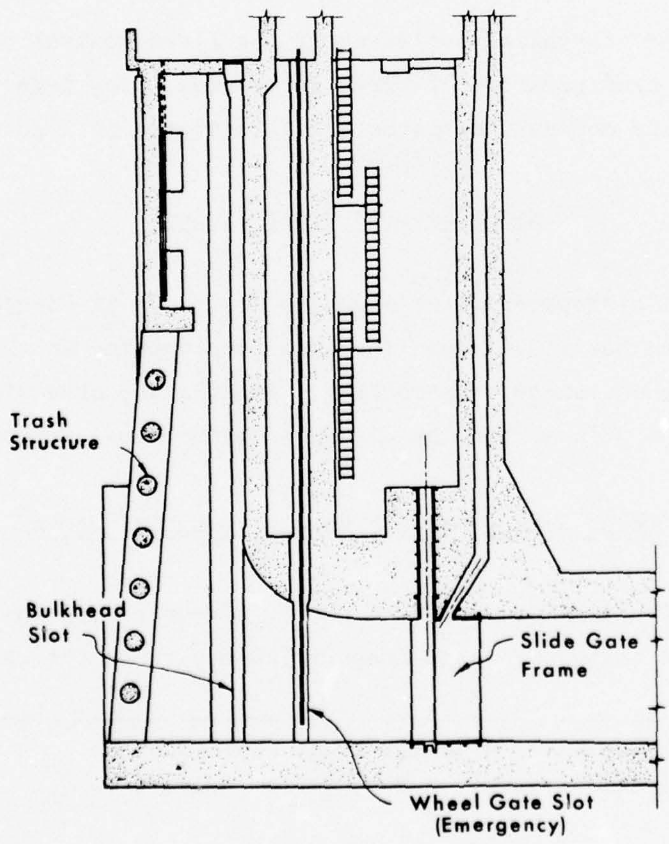

Figure 2. Chatfield Dam outlet works

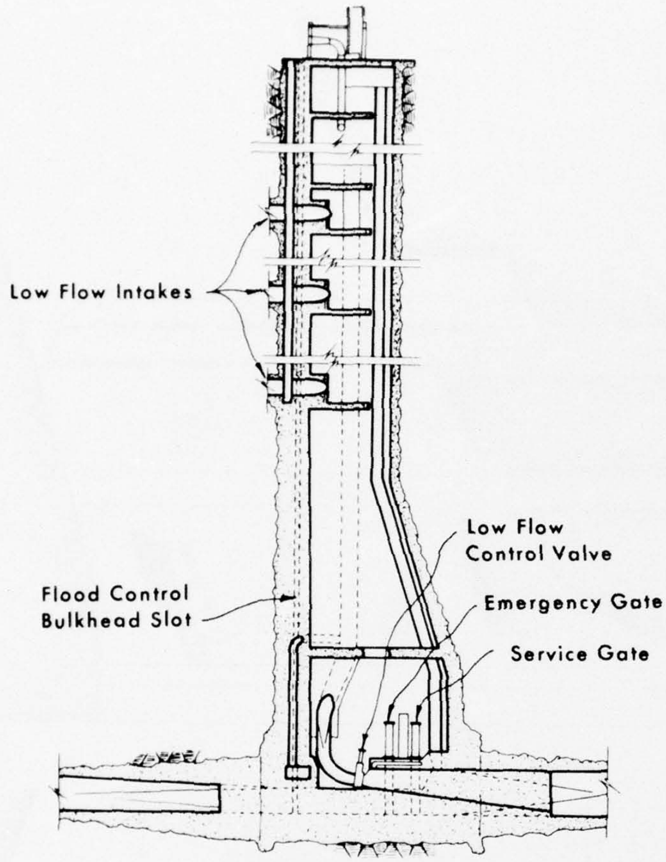

Figure 3. Warm Springs Dam outlet works

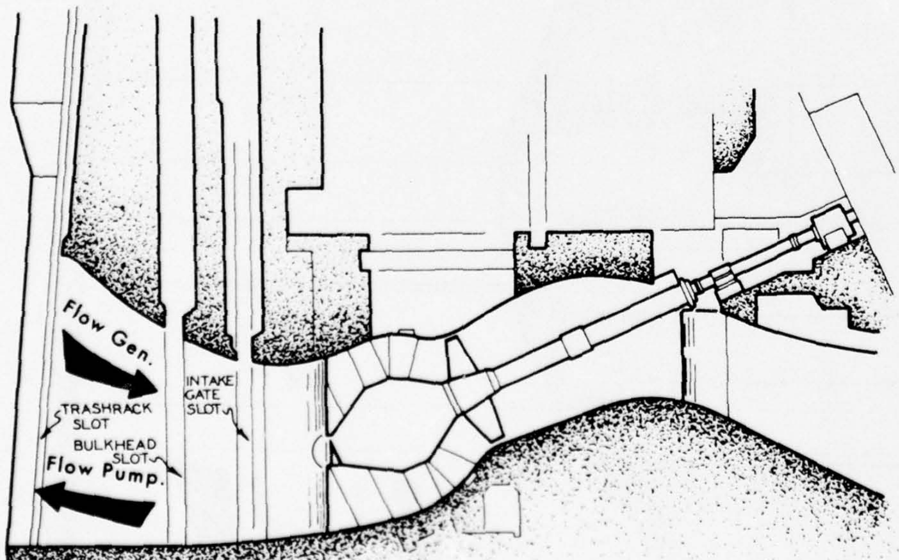

Figure 4. Harry S. Truman Dam pump-turbine

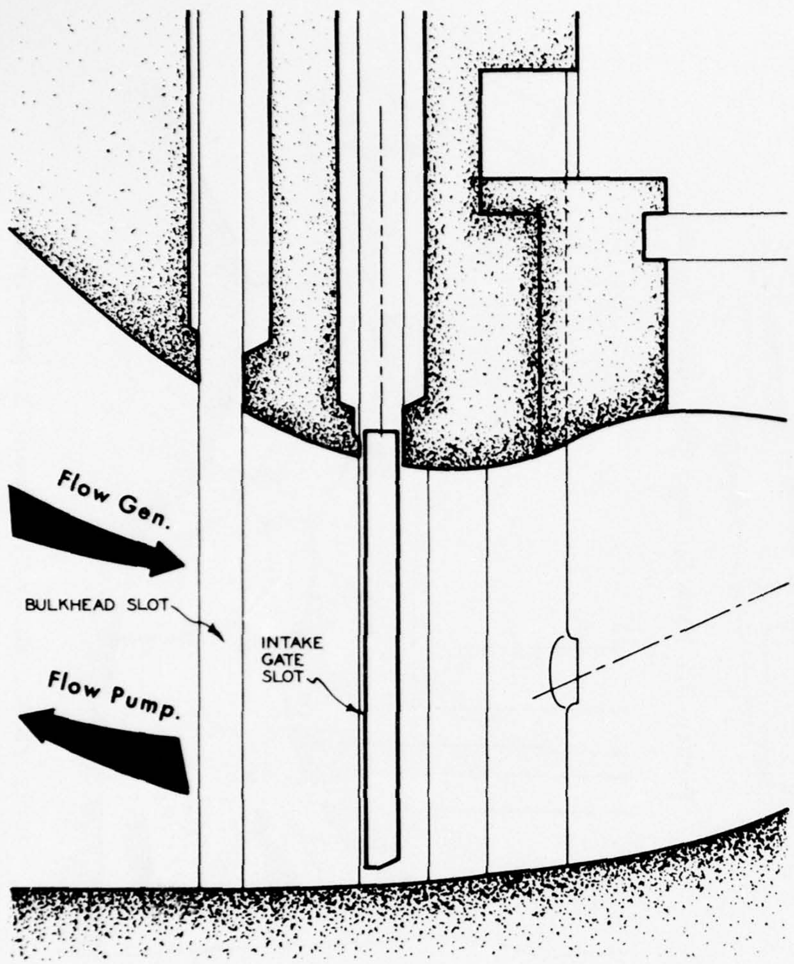

Figure 5. Harry S. Truman Dam intake

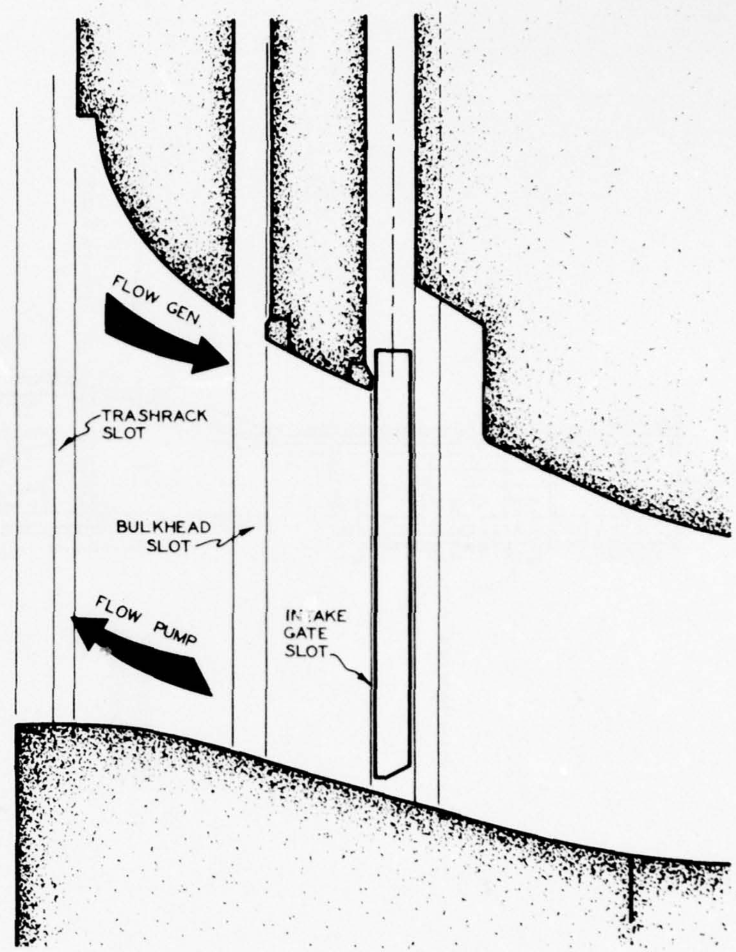

Figure 6. Clarence Cannon Dam intake

would not pass through the gate passages. The trash structure should prevent debris larger than 2/3 of the minimum gate dimension from entering. Only in special cases, where large debris is absent from the reservoir and watershed, should the trash structure be omitted. The usual trash structure consists of horizontal and upright beams, with the upright beams inclined slightly downstream from the vertical to facilitate raking. Concrete struts or concrete encased I-beams of streamlined shape are used to stop large trees. Another satisfactory grillage consists of horizontal concrete struts supporting vertical 6-in. steel pipes spaced at approximately 3-ft intervals. The area of the openings in the trash structure should limit the average velocity to not more than 10 to 15 fps. The structure is designed to withstand hydraulic pressure based on the depth of submergence with a minimum design differential head of 5 ft. For low head intakes, stresses due to complete stoppage and full head should be investigated and should not exceed 150% of normal stresses.

Structural Design of Hydropower Unit Trashracks

Trashracks are critical for hydropower projects because of the potential damage to turbines which can be caused by trash penetration. A designer of trashracks for pump-turbine units should consider at least the following general areas: differential design head, trashrack bar spacing, head loss, vibration, and materials.

Differential design head

Intake trashracks are usually designed for an unbalanced head of 10 to 20 ft of water. Draft tube trashracks for pump turbine units are designed for a lower 5-ft differential head because trash buildup is less likely in the draft tube area. Trashracks for "generating only" units are designed in the conventional manner (Figure 7), but the intake trashracks for the pump-turbine units are designed to accommodate the higher velocities which are present during the pumping mode. A dummy wedge and trashrack wedging system are desirable on the pump-turbine unit trashrack to prevent upstream-downstream movement due to flow reversal. The wedging system on the pump-turbine unit trashracks

as shown (Figure 8) will force the trashrack to bear alternately on the upstream and downstream faces of the slot.

Trashrack bar spacing

Water velocities at the trashracks should be no more than 4 fps for low pressure intakes and a maximum of 10 fps for high pressure intakes. The clear opening between trashrack bars is governed by the minimum fixed opening in the water passage that the trashrack is designed to protect, or the size of debris that can be sheared by the unit without causing damage. The clear opening generally varies from 2 to 6 in. or more, depending on the size and type of turbine and the minimum operating clearances. Bar thickness should be consistent with structural design requirements for both differential head and flow velocity (which could cause the bars to vibrate). The depth of the bar is primarily determined by the allowable working stress and the design differential head. The thickness is primarily a function of the velocity as is required to prevent vibration.

Vibrations

The pump-turbine unit has brought the trashrack vibration problems into sharp focus because of the possibility of a submerged jet causing a high-velocity flow. There are three basic areas to investigate when considering trashrack vibrations: The natural frequency of the trashrack bars; the forcing or driving frequency; and the possibility of resonance developing. Vibration problems start to develop as the two frequencies approach a resonant condition.

Pump-turbine forcing frequency. Forcing frequencies originating at the pump turbine will generally be produced as a product of the number of buckets and the revolutions per minute of the unit. Although a limited amount of information is available on this subject, effort should be made to avoid designing trashrack bars with a natural frequency that may produce a near resonant condition with a disturbance generated by the unit.

Vortex-shedding forcing frequency. The other type of forcing frequency is the one caused by the vortex-shedding phenomena at the downstream edge of the trashrack bar. Extreme caution should be

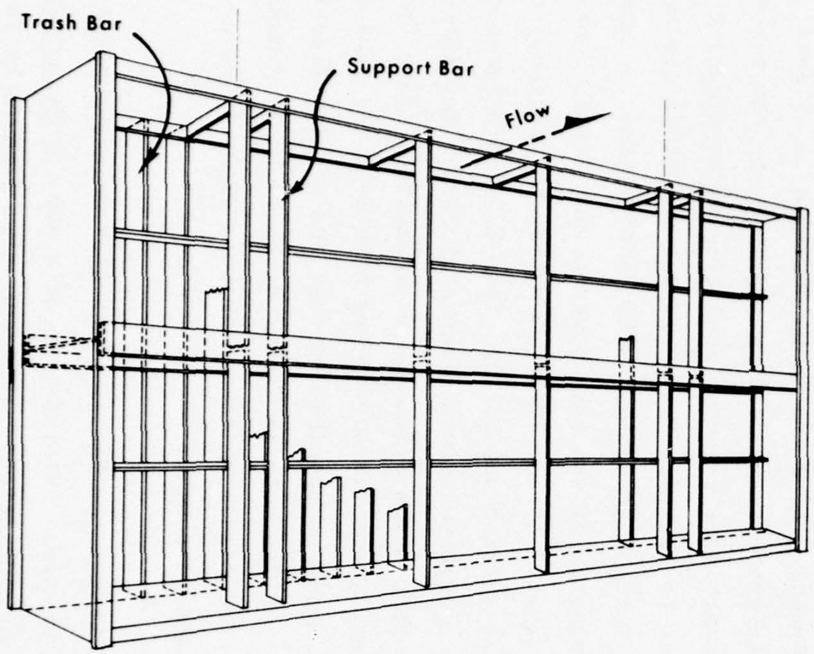

Figure 7. Gavins Point Dam intake trashracks

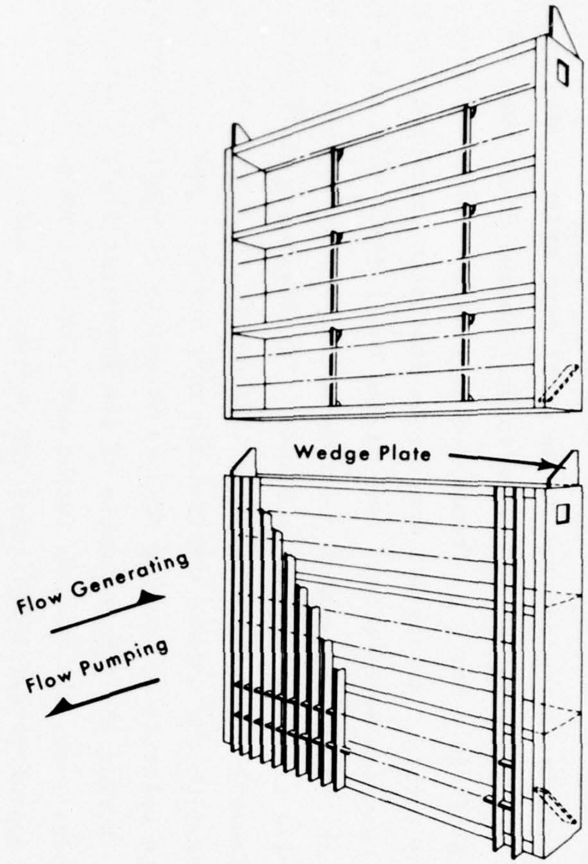

Figure 8. Harry S. Truman Dam intake trashracks

exercised in selecting a velocity for determining the forcing frequency. The average velocity and the maximum local velocity may be quite different, particularly during runaway in the draft tube area. Tests on the gross velocity distribution at Gavins Point (Kaplan) draft tube and Kaysinger Bluff (now Harry S. Truman) model (inclined-axis modified Kaplan pump turbine) intake and draft tube indicated approximately the magnitude that can be expected. The Gavins Point draft tube tests indicated that the maximum velocity during normal operation could be as high as 2-1/4 times the average velocity. The Kaysinger Bluff (now Harry S. Truman) model tests revealed that during the generating cycle normal operation the maximum local draft tube velocity was 3-1/3 times the average velocity and during runaway it was 4-1/4 times the average velocity. During the pumping cycle of the Kaysinger Bluff (Harry S. Truman) model test, the maximum intake velocity (discharge side of the pump) was approximately 1-3/4 times the average velocity.

Resonance. If a resonant condition is allowed to develop, the bar will vibrate with increasing amplitude as the resonant frequency is approached. If a resonant condition is permitted to exist, the bars may fail due to fatigue. The resonant condition can be avoided by having the forcing frequency sufficiently larger or smaller than the natural frequency of the bar; however, for design considerations, it should be limited to the latter. A forcing frequency to natural frequency (f_f/f_n) ratio not greater than 0.30 is suggested for design. The problems associated with trashrack design in high-velocity flow are many, with some areas still not well defined. If a trashrack were to be designed purely for vibration consideration, the bars would probably be as nearly square as possible so that the forcing frequency would be at a minimum, and the natural frequency would be at a maximum. Because of the associated high head loss with this type of design, a compromise bar configuration is sought.

Material

Trashracks for "generating only" unit are fabricated from structural carbon steel conforming to ASTM A36 for Structural Steel, with an allowable working stress of 22,000 psi. Trashracks for pump-turbine

units are fabricated from hot rolled steel conforming to ASTM A588 for High-Strength Low-Alloy Structural Steel with 50,000 psi Minimum Yield Point to 4 in. Thick. The allowable stress is limited to 18,000 psi to provide greater rigidity.

Pump-turbine unit velocity

The maximum design velocity for pump-turbine unit trashracks is based on the maximum pumping discharge velocity as determined from model tests and assuming that a submerged jet from the spiral case acts on the trashrack.

Corrosion Protection

A corrosion allowance of 1/16 in. is provided on each side of the pump-turbine trashrack bars. This is done because of the critical relationship between thickness of the trashrack bar and vibration. Trashracks frames, embedded in concrete, consist of welded corrosion-resisting steel plates on the exposed side.

Trashrack Cleaning

The extent to which trashrack cleaning must be accomplished is dependent upon the type of inlet and the function of the installation. Obviously the accumulation of debris at a power generating installation is more critical than at an outlet works because head loss across the trashracks of a generating plant can be translated into loss of revenue.

Trashrack Failures

These failures have occurred throughout our country. Until recently little attention was given to the trashrack vibration consideration. Failures have been recorded anywhere from 6 months to 20 years after the installation was placed in operation. At the Omaha District's Fort Randall and Gavins Point projects, bars have broken out of trashracks because the accumulation of debris caused an increase in the

velocity sufficient to force some of the bars to vibrate (Figure A-7). See Appendix A.

Adaptability of Trashrack Design to Computer Programming

We are not aware of any program for complete design of a trashrack; however, a grid analysis has been effectively used by some District offices. Portions of the design procedure could be programmed. With Corps-wide usage, a computer program for trashrack design would be feasible.

Bulkheads or Stop Logs

These are usually provided just upstream from the gates so that the gate slots may be unwatered for inspections and maintenance operations. See Figure 9. Bulkhead and stop log requirements are the subject of a separate paper in this session.

Corps of Engineers Gate Requirements

Function

For an outlet works on a flood control project, gates are normally provided to control or regulate the normal or emergency releases. Gates for water passages in hydroelectric power projects are not required for regulation and are therefore normally in the fully open or closed position.

Types of gates and gate selection

Gate type information showing the variety of gate designs available is in the following tabulation. Gate selection is made on the basis of operating head, safety, hydraulic efficiency, reliability, adaptability, and operation and maintenance costs.

The principal types of regulating gates on Corps of Engineers dams for heads 100 ft or more are hydraulic slide, hydraulic roller, hydraulic wheel, and hydraulic tainter gates. Heads of 300 to 400 ft

Gate Characteristics

Gate Types	Maximum Height ft	Emerg.	Service	Notes
Unbonneted slide gates	75	X	X	
Bonneted slide gate (old)	100	X	X	Hydraulic hoist
Bonneted slide gate (new)	350	X	X	Pressure in bonnet
Jet-flow gates	500	No	X	Very little pressure in bonnet
Top seal radial gates	250	No	X	
Ring follower (slide) gates	500	X	No	
Wheel & roller mounted gates	500	X	No	(Also called "Fixed Wheel")
(Head limited by quality of seals)		(Closed by gravity)		
Fixed cone (Howell & Bunger)	1000	No	X	Okay submerged
Hollow jet valves	1000	No	X	Not for submergence
Needle valves	2000	No	X	Has been replaced by cone & jet valves
Tube valves	2000	No	X	Same as needle, w/o needle
Sleeve valves	250	No	X	For submergence
Butterfly valves		X	Seldom	
Spherical & plug valves		X	No	

could be used with properly designed passages using steel liners.

Hydraulic slide gates have a record of dependability and low maintenance, and are advantageous for fine regulation. They have been used on heads up to approximately 300 ft. They are limited to smaller sizes (approximately 8 by 16 ft) than roller, wheel, and tainter gates

because of the much greater operating force required per square foot of gate and the greater rigidity required.

Roller (Caterpillar) or wheel gates with cable hoists have been used in excess of 200 ft of head. They are not as positive for fine regulation as other gates because of the elasticity of the cables.

Hydraulically actuated roller or wheel gates with rigid connections have been used in excess of 200-ft head. They have shown substantial economy in some recent installations, partly because the bonnet has been eliminated by putting the gate in a wet well. They are satisfactory for fine regulation.

Hydraulic tainter gates have been used in excess of 200-ft head. They have shown economy and are satisfactory for fine regulation.

Requirements for flood control projects

Service gates. In order to provide sufficient operating flexibility, not less than two service gates located in separate water passages should be provided for the outlet works. The number of gates and the gate area should be such that in the event of one inoperable gate, the reservoir operation will not be seriously affected.

Emergency gates. Emergency gates are required in projects having a water conservation pool to prevent loss of stored water in case the service gate is inoperable. They should be located in the intake structure immediately upstream of the service gates. The operational characteristics of emergency gates must be such as to perform the function of service gates, until the service gate is restored. Emergency gates must be designed to withstand the load of the maximum reservoir head.

Requirements for hydroelectric projects

Provision for emergency type closure of the intake downstream from the racks is necessary to protect the generator unit. A vertical lift gate (referred to as "intake gate") in each water passage is usually provided and is normally suspended just above the roof of the

intake from a fixed hoist; however, on a few projects the intake gantry crane positions the intake gate. Self-closing roller or wheel gates capable of operating under full flow are required.

Roller, wheel, and slide gates

These are the types of vertical lift gates most commonly used by the Corps of Engineers. The remainder of this paper will be devoted to a discussion of the design of these three types of gates.

Roller Gates

General

The roller gate (Figure 10) also known as "tractor" or "caterpillar" gate, is the type of vertical lift gate in which the lateral loads are supported by one or more pairs of endless trains of small rollers mounted on the end girders. Roller gates are usually suspended by cables and can be closed by gravity under full flow. They are most commonly used as intake gates for hydropower projects. For all but the lowest head intakes these caterpillar-type gates with corrosion-resisting steel rollers and tracks have been found to be the most economical.

Special design considerations

Vibration is a matter of concern in the design of the suspended roller gates.

Downward forces on a partially opened gate create hoist problems in both hydraulically operated gates and in cable-suspended gates.

Wheel Gates

General

A wheel gate (Figure 11), also called a "fixed wheel" gate, is the type of vertical lift gate in which lateral loads are supported by several wheels, each on an individual axle. Wheel gates are also usually suspended by cables and can be closed by gravity under full

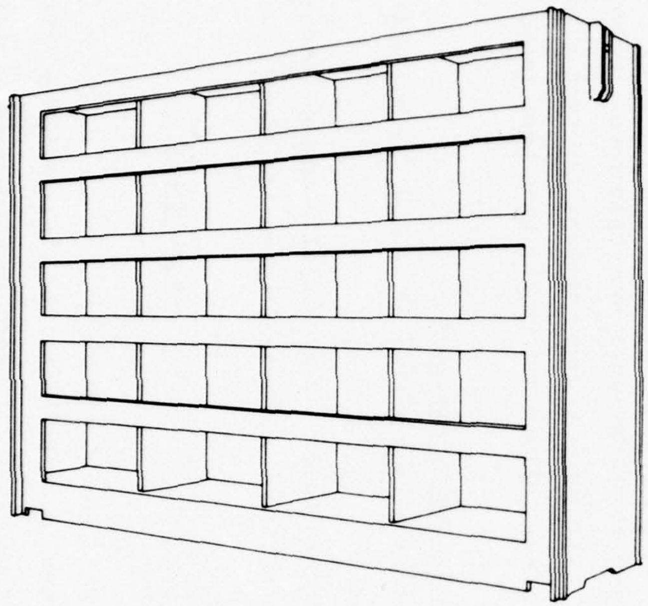

Figure 9. Clarence Cannon Dam intake bulkhead

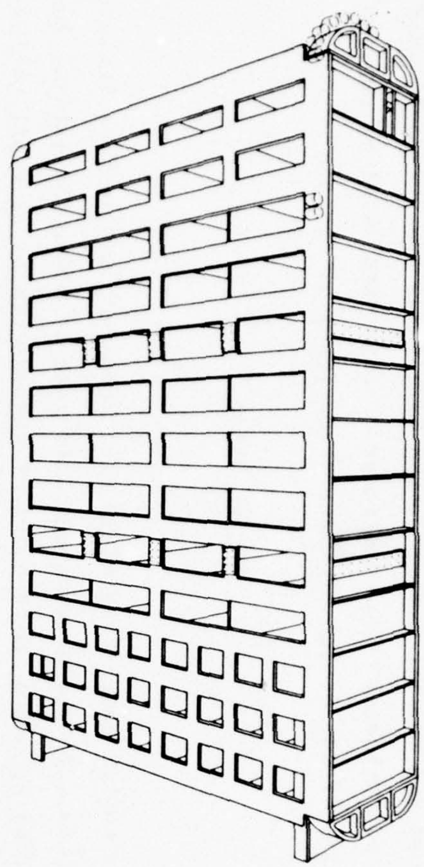

Figure 10. Harry S. Truman Dam intake roller gate

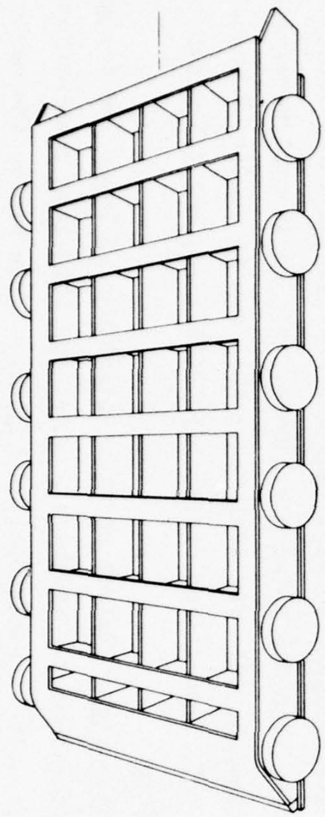

Figure 11. Chatfield Dam emergency wheel gate

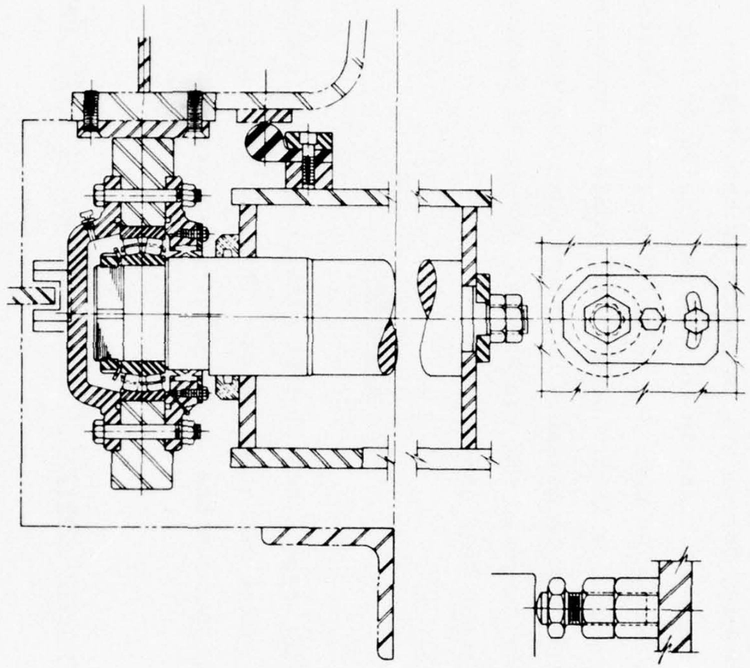

Figure 12. Chatfield Dam wheel gate

flow. Like roller gates, they are most commonly used as intake gates for hydropower projects.

Special design considerations

The vibration of the suspended gate and the hoist problems created by downward forces are on partially opened gates. An important advantage of the wheel gate is that it is adapted to long spans because provision can easily be made for rotation of the end bearings due to deflection of the gate leaf. Each wheel should be independently supported on an axle which can be adjusted to insure that the wheel load is uniformly distributed to all the wheels. Figure 12 shows an eccentric type of adjustment that can be used.

Slide Gates

The slide-type vertical lift gate design requirements are similar to those for roller and wheel gates. The greater operating friction does limit the maximum head. The slide gates are usually hydraulically operated.

Structural Design of Roller, Wheel, and Slide Gates

Design loads

Gates are designed to withstand (a) horizontal water load, (b) horizontal water load due to wave pressure, (c) horizontal water load due to ice pressure, (d) vertical water load due to uplift, downpull, or overflow, (e) impact from drift, (f) dead load, and (g) wind.

Design procedure

Load selection. Select usual combinations of loads and design at normal unit stresses. Select all other possible load combinations and design for unit stresses 33-1/3% higher. For example, the maximum horizontal water load in combination with dead load is considered normal, but if ice or wave pressure is added, the allowable unit stresses may be exceeded.

Closing forces. The gate should be so designed that the forces causing closure of the gate exceed the forces resisting closure by not less than 25%. The closing forces on wheel and roller gates consist of the gate weight in water and the hydraulic forces acting downward on the gate.

Gate elements

Gate leaf. The gate leaf consists of a welded framework of built-up beams for supporting the skin plate. Material for the gate leaf is structural carbon steel conforming to ASTM A36 for Structural Steel.

Roller train. The roller train, consisting of hardening corrosion-resisting steel rollers and pins, travels on a corrosion-resisting steel track.

Gate seals. The seals are of molded rubber.

Corrosion protection

No corrosion allowance is made on any structural member. All of the exposed carbon steel surfaces of the intake gate will be field painted. Usually, magnesium anodes are provided to mitigate corrosion of the carbon steel which would result from galvanic action between the carbon and corrosion-resisting steels. The magnesium anodes are supported in a position adjacent to the corrosion-resisting steel roller trains, seal holders, and seal bars. The anodes are located as close as practicable to the corrosion-resisting steel parts to achieve polarization with an efficient distribution of protective current.

Gate Catapulting

The phenomenon of catapulting gates deserves close attention. Upstream seal-type roller gates have been known to suddenly thrust upward following cracking of the gate during the "watering-up" operation. See Appendix B for descriptions of actual catapulting incidents.

A prime consideration is the configuration of the lower end of the gate slot where it intersects the top of the water passage. A comparison of that portion of the gate slot for Harry S. Truman (Figure 5) and Clarence Cannon Dam (Figure 6) shows how the improved configuration of

Clarence Cannon places the restriction above the gate which causes a pressure to develop on top of the gate to prevent the gate from catapulting.

Consideration should also be given to existing installations to avoid operation conditions which, although not obvious, could cause the gate to catapult. Example: Suppose debris prevented the intake gate from being completely lowered and sealed. Also, suppose the wicket gates were opened to unwater the unit. After it was realized that the gate was not sealed and unwatering was not possible, assume the wicket gates are closed. This would then become similar to a watering-up operation with the amount of gate cracking (opening) dependent on the debris present. This could conceivably present a more severe condition than the normal watering-up procedure.

Adaptability of Design Process to Computer Programming

To our knowledge there are no published programs for a complete gate design. Programming on a District level has not been economically feasible because of the limited need and the relative brevity of the gate computations. With the proposed centralization of programs where one program would be used Corps-wide, the programming of structural computation for gate design is feasible.

References

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2. EM 1110-2-2101 Working Stresses for Structural Design.
3. EM 1110-2-2400 Structural Design of Spillways and Outlet Works.
4. EM 1110-2-1602 Hydraulic Design of Reservoir Outlet Structures.
5. EM 1110-2-2701 Vertical Lift Crest Gates.
6. EM 1110-2-3001 Planning and Design of Hydroelectric Power Plant Structures.
7. EM 1110-2-3400 Paint Manual

8. ETL 1110-1-67 Structural Welding Code.

9. ETL 1110-2-2 (Feb 66) Emergency Gates for Outlet Structures

10. ETL 1110-2-54 (Aug 68) Outlet Works, Intake-Bulkhead Slats.

11. ETL 1110-2-92 (May 70) Watertightness Tests - Gate Skin Plates.

12. ETL 1110-2-125 (Jun 71) Application of San Fernando Earthquake Experience to Earth Dam Design.

13. ETL 1110-2-175 (Jan 74) Hydraulic Design Conferences (1971-1972).

Appendix A: Trashrack Failures

Trashrack Failures

Figures A1-A6 illustrate a classic example of trashrack bar failure. This occurred at the Gavins Point Dam, a hydropower dam on the Missouri River in South Dakota.

The bar failure is attributed to excessive vibration caused by extraordinarily high velocities when trash buildup restricted the normal flow.

Figure A7 illustrates flow patterns at Gavins Point Dam.

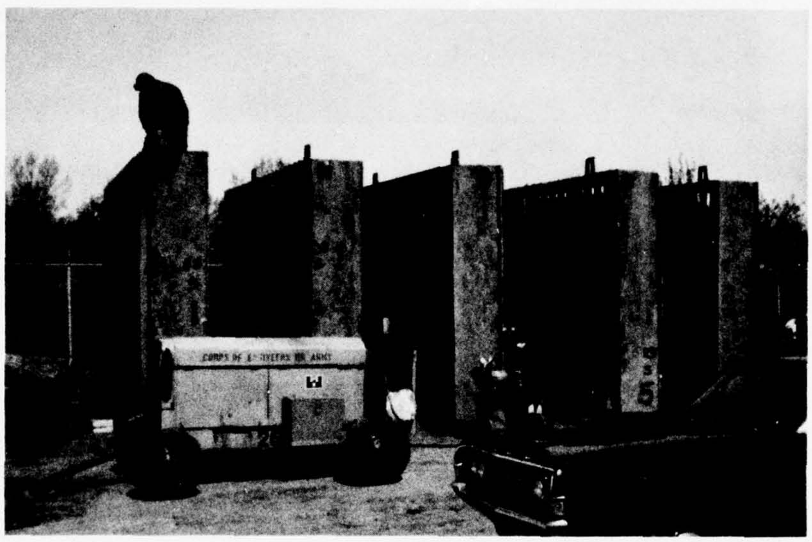

Figure A1. Trashrack repair operation at Gavins Point Dam

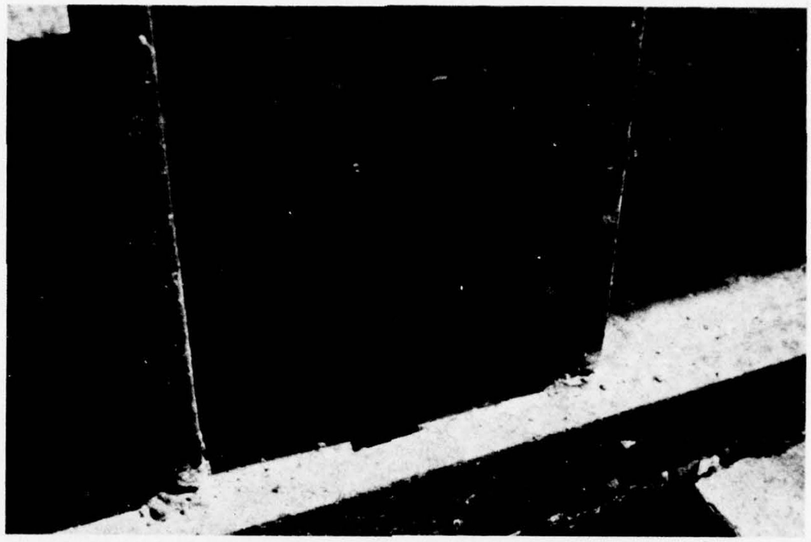

Figure A2. Typical rear support bar failure--top end attached, bottom free at lower end

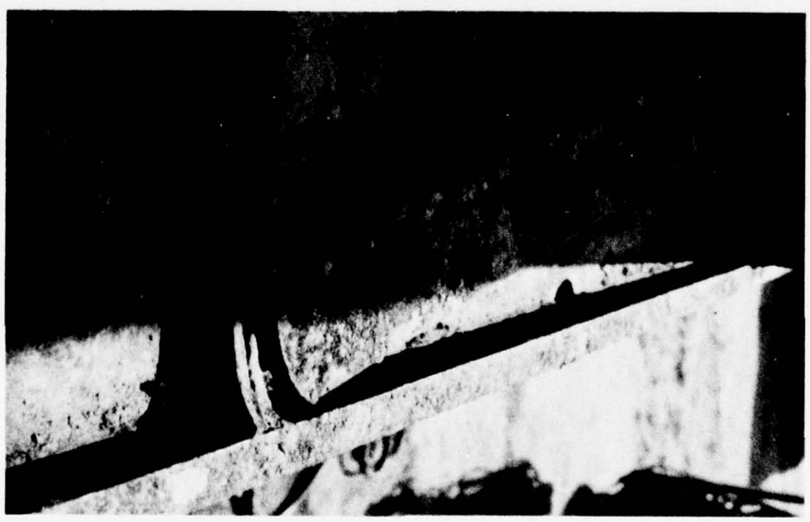

Figure A3. Typical rear support bar failure at both ends; lower end shown

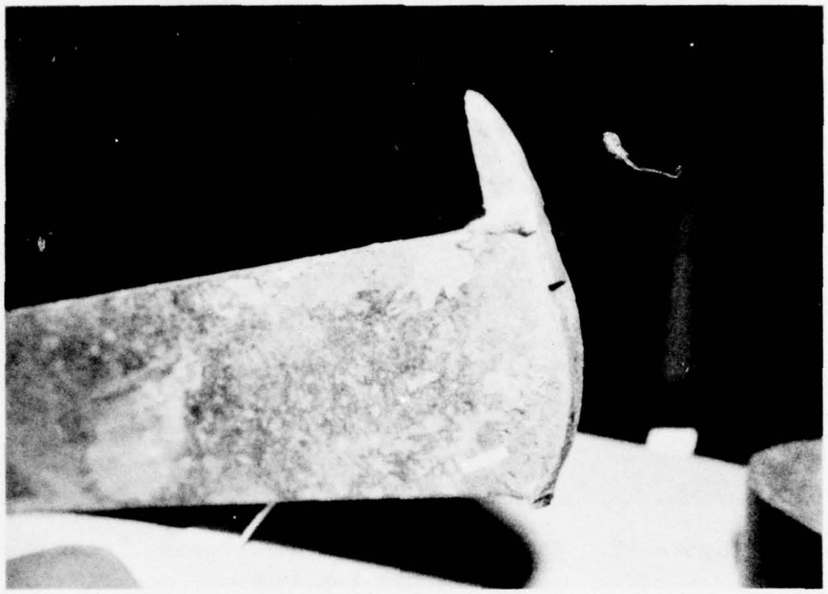

Figure A4. Broken bar showing portion of beam attached

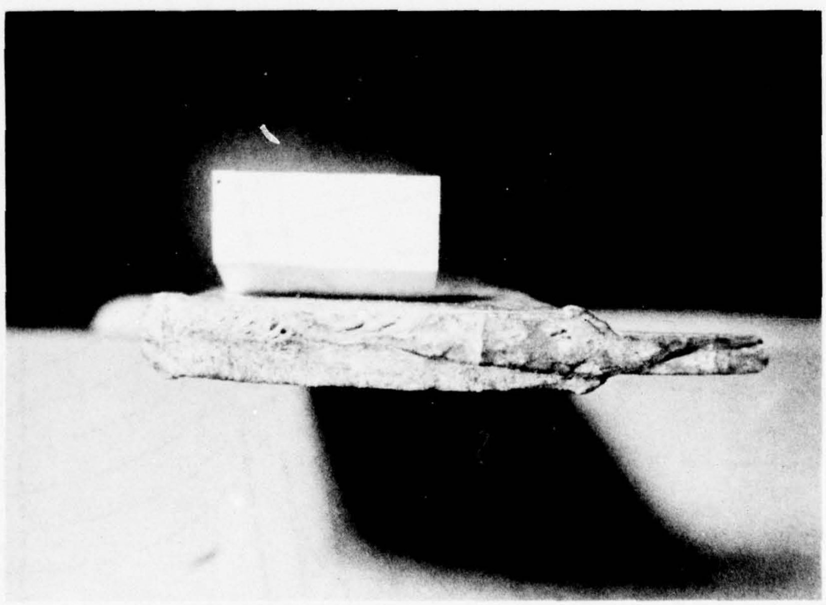

Figure A5. Typical end view of broken rear support bar

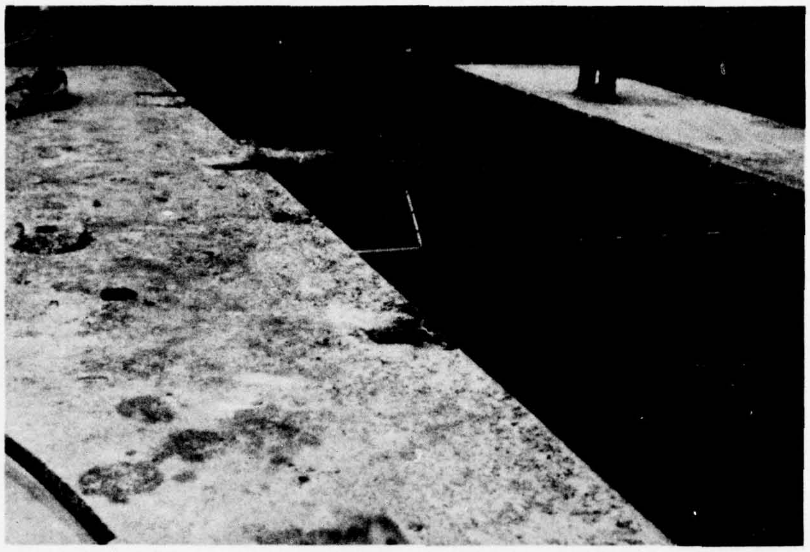

Figure A6. Top view of trashrack showing holes for support bar replacement

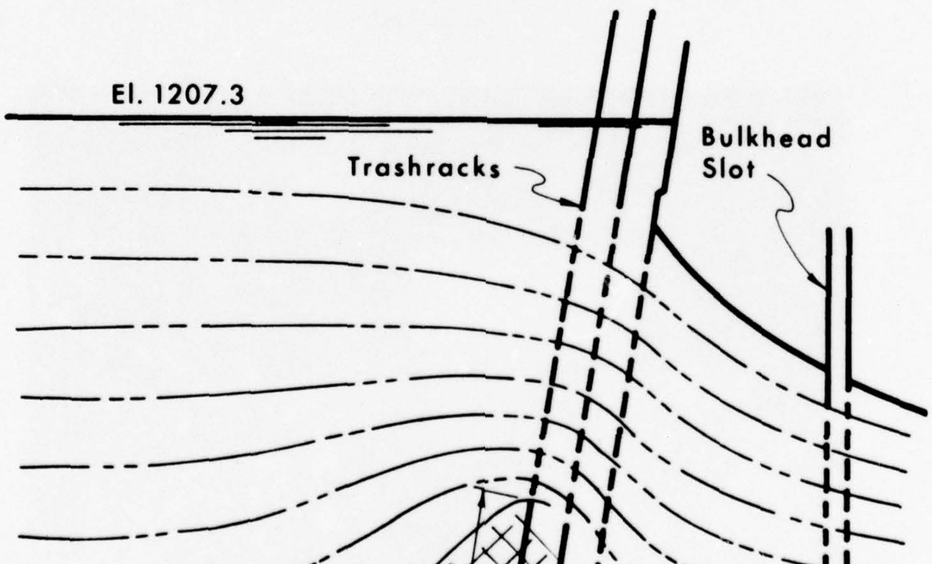

Figure A7. Gavins Point flow streamlines

Appendix B: Gate Catapulting

Gate Catapulting

The phenomenon of gate catapulting must be considered when designing gates and gate wells. Roller gates with upstream seals have been known to be suddenly catapulted upward in the gate slot during the watering-up procedure.

On 27 June 1968 at the Mossyrock Dam, a 145,000-lb roller gate with upstream seals catapulted approximately 50 ft up the gate slot. The dam is owned and operated by the city of Tacoma, Washington. The intake gate and hoist-lifting beam mechanism suffered extensive damage.

On 13 September 1974, a 27,700-lb gate of similar design catapulted 249 ft up the slot. This occurred at the Corps of Engineers Dworshak Dam. Fortunately, only minor damage resulted because the gate lodged in the top of the gate slot after 75% of the gate was exposed above the roadway. After the upper portion of the gate passed out of the gate slot, the upper guide shoes were no longer supported and consequently, the gate leaned over sufficiently to lodge in the slot. This resulted in damage to the lower gate guide shoes. After minor repairs, the gate was placed back in operation. Figures B1-B3 show the condition of the gate as a result of the catapult.

The Waterways Experiment Station is presently conducting intake gate catapult tests jointly for the St. Louis, Kansas City, and Omaha Districts. Figure B4 shows a model catapult test in progress at WES.

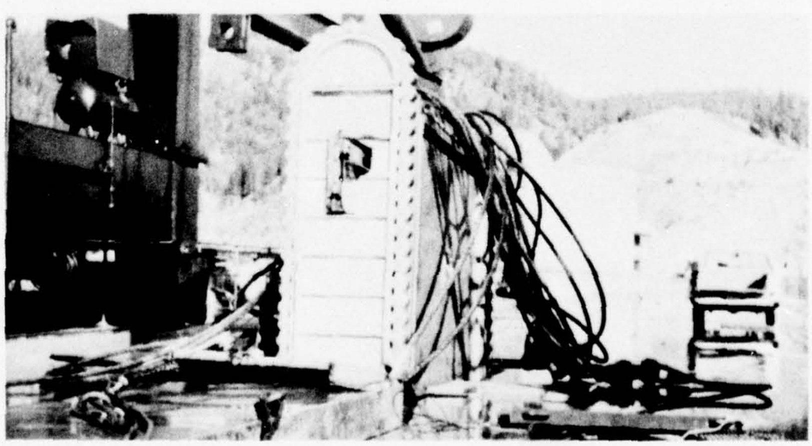

Figure B1. Dworshak Dam intake gate after catapult

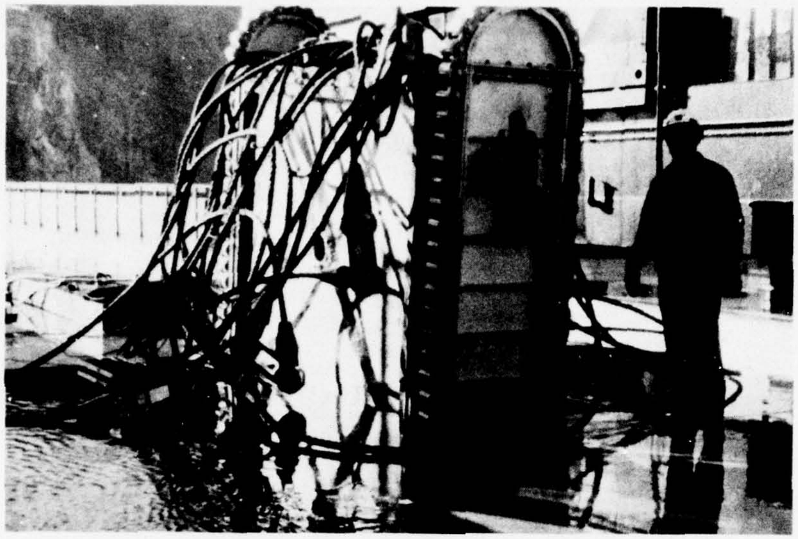

Figure B2. Closeup view of Dworshak Dam intake gate after catapult

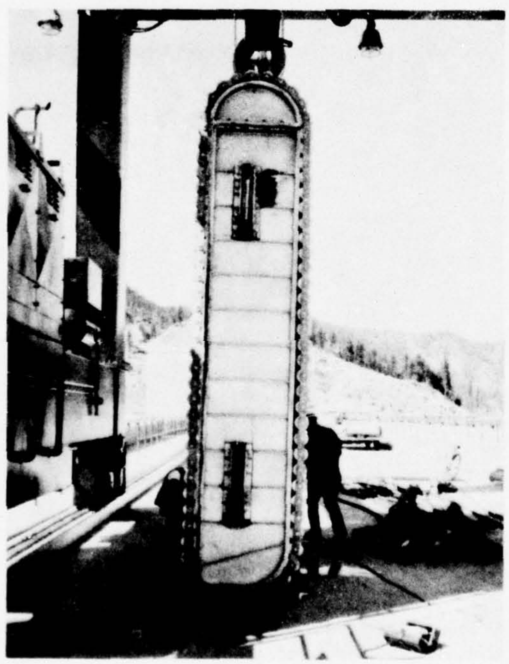

Figure B3. Bulkhead gate on deck for damage inspection

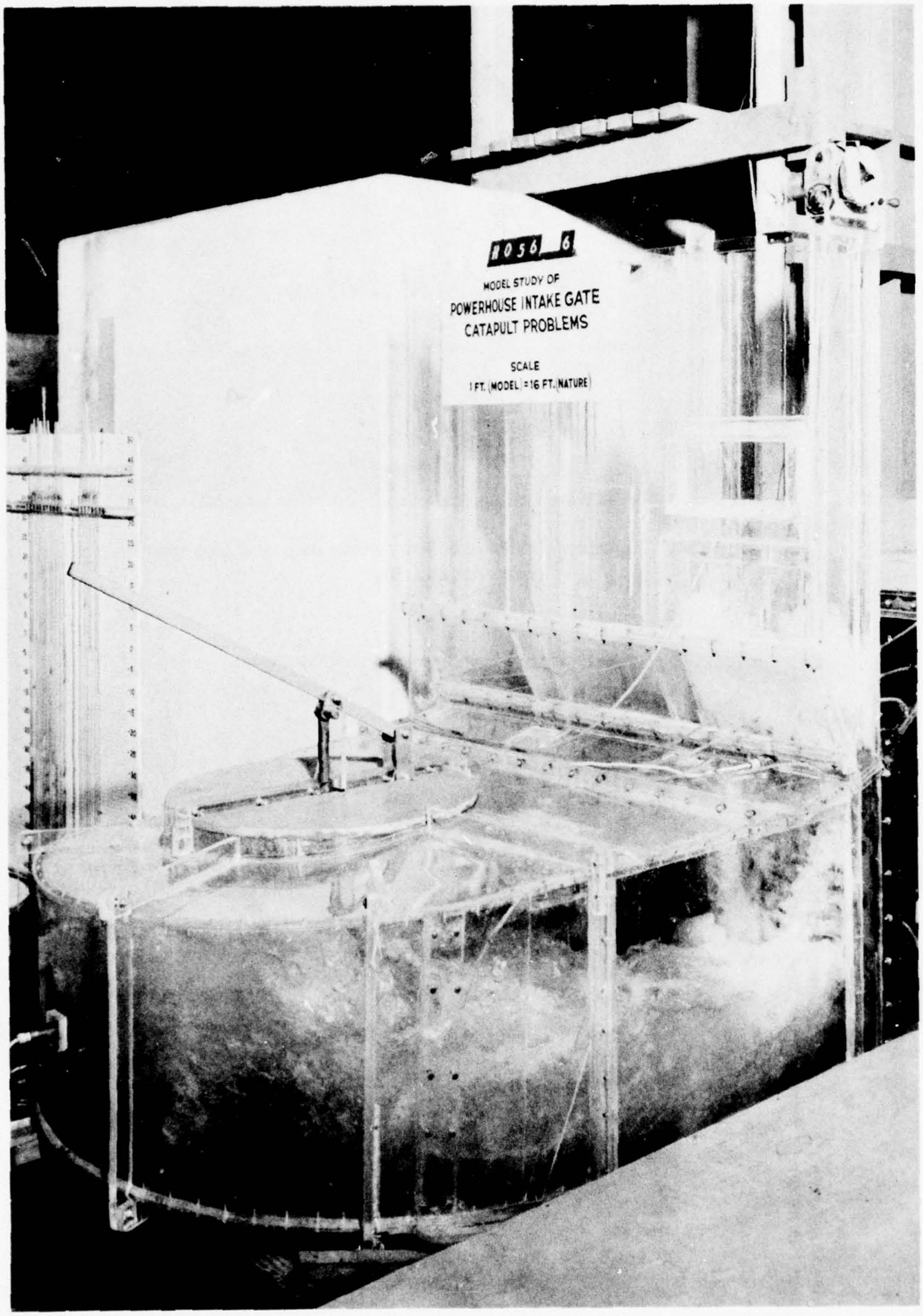

Figure B4. WES model showing watering-up operation

STATE-OF-THE-CORPS-ART, MITER GATES AND STOP LOGS

by

James D. Gibson, Jr.*

Miter Gates

Design philosophy

Normally, miter gates are used for navigation locks, serving to fill and empty the lock chamber. Walkways installed on top of the gates provide access from one lock wall to the other. Many of the moderate- and high-lift locks in the United States are equipped with double-leaf miter gates. These gates are fairly simple in construction and operation, are low in maintenance costs, and can be opened or closed more rapidly than any other type of gate. However, in an emergency situation with appreciable unbalanced heads on the two sides of the gate, they cannot be used to close off flow.

In the past miter gates have been framed either horizontally or vertically. When the gates are horizontally framed, all the water load is transmitted through the girders and quoin blocking into the gate monoliths. With vertically framed gates, part of the water load is carried by the top girder to the gate monoliths and the remaining part of the load is carried directly into the gate sill.

Horizontally framed miter gates are superior because of their rigidity. Past studies of the costs of both types indicate that horizontally framed gates cost very little more than vertically framed gates; the lesser weight of the vertically framed gate is offset by its greater fabrication cost. Due to the greater rigidity of the horizontally framed gate and the insignificant difference in cost, the vertically framed gate will no longer be used except for unusual applications.

Horizontally framed miter gates, when the leaves are in the mitered position, form a three-hinged arch. With the gate in a mitered position, gate geometry is a function of the angle the working

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* Session Chairman, Structural Engineer, Mobile District.

line of the leaf makes with a line normal to the lock walls. Past study and design indicate that a slope of 1V on 3H gives the best results.

The approximate ratio of height to length, where the weight of a vertically framed gate is essentially the same as a horizontally framed gate, is somewhere between 0.70 and 1.0. This does not, in itself, indicate the dividing line between vertically and horizontally framed gates. Due to the greater rigidity of the horizontally framed gate it is more desirable in most cases, even with a slight increase in cost, than the vertically framed gate.

The pintle is located so that the leaf, when recessed, is completely within the lock wall; the pintle is eccentric (upstream) with respect to the center of curvature of the bearing face of the quoin contact block. The center of curvature of the bearing face is always located on the line tangent to the thrust line at the quoin contact point. The pintle eccentricity makes the quoin block approach the point tangentially, thereby reducing the possibility of metal interference.

Gate reactions are basically divided into two categories, one, with the gate in the open or intermediate position with no water load, or two, with the leaves mitered and supporting the full hydrostatic load.

Without the water load the reactions are couple forces, applied at the gudgeon pin at the top and the pintle at the bottom. The top couple force is made up of deadweight forces combined with the operating strut forces. The bottom, or pintle forces, are generally concerned only with the deadweight of the leaf which may include ice and mud.

With the gate mitered and the full hydrostatic load applied, each horizontal girder carries a portion of the water force to the wall monoliths.

The following symbols are used to describe the various components of the gate loads.

R = reaction of the girder on the wall quoin

N = vertical component of R (vertical and horizontal are used to indicate forces or dimensions perpendicular and parallel to the work line of the leaf)

P_1 = horizontal component of R

P_2 = the corresponding water force on the end of each girder, determined from the water pressure on the surface perpendicular to the work line of the leaf, with this surface extending from the contact point to the upstream side of the skin plate

W = total corresponding water force of each girder, determined by the pressure and the length of the leaf, adjusted by the effective width of damming surface

The skin plate is located on the upstream face of the girders and is designed for the water load, with edges of panels assumed fixed at the center line of intercostals and the edges of the girder flanges; the point of support is assumed to be never more than 6 in. from the center line of the girder web. This distance is being changed to 4 in. for smaller gates and the upper sections of lower gates where the minimum 8-in. flange width may be encountered.

The skin plate is also considered an effective part of the upstream girder flange. When a section has a skin plate of a higher yield than the rest of the girder, the effective width of skin plate shall be determined by the higher yield point.

Because of the combined loading, the skin plate shall be checked for biaxial stress, which is composed of skin plate action and beam action. Mohr's circle is a convenient method of determining the combined stress, with shear being the only significant value. Principal stress will not increase.

Intercostals are designed as vertical beams supported at the center line of girder webs. They are generally designed as simple beams, thereby providing additional strength against impact. Normally, the maximum size intercostal is used throughout the leaf, including

thrust diaphragm and end diaphragm stiffeners. On the higher lift gates it may be desirable to change intercostal size.

An effective section of skin plate is assumed as acting with the intercostal; an average water pressure is used for design loadings.

End diaphragms are designed as panels acting as skin plate, with the effective panel being between the stiffener angle and the next lower girder. Except for loads from jacking supports, the diaphragms have no definite axial design load. They do serve to distribute impact loads and to stiffen the leaf by tying the girders together. On the smaller gates, diaphragms are made a minimum of 3/8 in.; the minimum for the larger gates is 1/2 in. Generally, the end diaphragms are made a minimum of 1/2 in. for all size gates.

Horizontal girders lie along a chord of the thrust line curve; the resulting eccentricity of thrust produces bending stress in addition to the axial stress. The girders are so spaced that variation in the girder flange sizes and skin plate thicknesses are held to a minimum. The loads on each girder are determined by taking the average water load per linear foot of girder. While this gives a slight variation from a more exact loading, it is considered more than accurate enough for the usual gate loading.

The recommended procedure for design is to assume that each girder section has an effective length equal to the vertical diaphragm spacing. The ends can be assumed fixed and the value of K (effective length factor for compression members) can be taken as 0.65. The minimum radius of gyration, about the minor axis, should be used. The effective skin plate width (beyond the flange) is determined by the AISC Specifications Section on unstiffened elements under compression. The values of F_b (allowable compressive stress) are determined as if the girder section is an isolated girder of the length described above. Where the value of Kl/r (length/radius of gyration) is less than 40, the basic stress of 0.50 F_y (yield strength) can be used for F_b. On the top and bottom girders, the formula applicable to channels shall be used to determine the allowable bending stresses for either the upstream or downstream flange.

The thrust diaphragm is tangent to the thrust curve at the contact point and is approximately in line with the thrust curve between the contact point and the end diaphragm, which is the limit of the thrust plate. The thrust plate serves to distribute the reaction of the girders from the quoin block into the girder webs. It also acts as the damming surface between the end plate and the end diaphragm. Part of the thrust diaphragm is also considered effective in the quoin post, making the thrust plate subject to bearing, skin plate, and column action stresses. Shear between the web and thrust plate is to be checked also, but is not combined with the above-listed stresses. The bearing stress from the contact blocks is assumed to follow a 45-deg angle from a point midway between girders, up to the effective web section. The effective section consists of the web, flanges, and a portion of the thrust plate.

A section of the thrust diaphragms, vertically from top to bottom girders, form a column to support the deadweight of the leaf. The end plate and two vertical stiffeners form one flange of the column; a plate perpendicular to the thrust diaphragm, with vertical stiffeners on the outside edges, forms the other flange. The axial load on the quoin post consists of the deadweight of the leaf plus ice and mud load. The quoin post is subjected to both axial and bending stresses due to the eccentricity of the pintle and gudgeon pin.

The anchorage system supporting the top of the miter gate leaves is divided into three basic categories: (a) gudgeon pin barrel, (b) anchorage links, and (c) embedded anchorage, with the lower support consisting of pintle ball and base.

The gate leaves are operated by two basic types of machinery, one consisting of a hydraulic cylinder and rack assembly and the other the direct acting cylinder, in which the cylinder rod is connected directly to the leaf.

Diagonals are used on the downstream face of horizontally framed gates to counteract the torsional or twisting action of the leaves. Diagonals are designed so that all diagonals will be in tension under all normal operating deflections. Strain gages should be used to prestress the diagonals.

Miter blocks and quoin blocks are used to distribute the axial load of the horizontal girders into a uniform force transmitted into the mass concrete of the lock walls.

Mitering guides are used to minimize the difficulties of seating the miter blocks in the proper position.

Protective fenders are used on the downstream side of the gates to protect against impact and damage by passing tows when the gate is in the recess.

Cathodic protection is used to minimize the effects of corrosion and keep material thickness in the most economical and practical range.

Differences between
Corps and outside industry

Almost all miter gates are used with navigation locks and are constructed by Government agencies. Outside industry seldom designs miter gates unless it is working for the responsible Government agency. In these cases the work must conform to Government requirements and concepts for miter gate design.

The role of computers in design

A computer can be a very useful tool in the design of miter gates. Due to the very limited current use of vertically framed gates there are no known programs developed primarily for their design. Various programs have been used with limited success for the design of horizontally framed gates; the most recent and efficient program is one developed by the Mobile District. In this program the practical aspect of design has been combined with the efficiency and accuracy of the computer.

The general philosophy for designing the components of a miter gate involves generation of the component. A component of minimum size or thickness is initially used as a trial section. If the computed stresses exceed the allowable stresses, 1/16-in. thickness is added to the section and the stresses computed again. (In the case of stiffeners or intercostals, the computer goes to the next larger size.) This technique, taking a minimum size component and increasing it incrementally until it is acceptable, is followed throughout the program.

The Mobile District computer program, "Miter Gate Design," will compute or design the following items: (a) loads on girders in pounds per foot, (b) skin plate, (c) intercostals, (d) horizontal girder sections at center line and end diaphragm and the transition section between these points, (e) intermediate web stiffeners, (f) thrust diaphragm and stiffeners, (g) tapered end sections of girders, and (h) end diaphragm and stiffeners. (See Appendix A.)

Criteria to be selected by the designer for the use of the computer program consists of: (a) girder spacing, (b) number of vertical diaphragms, which gives the number of panels per girder, (c) intercostal spacing, which gives a number of spacings per panel between vertical diaphragms, (d) web depth and thickness (a partial run can be made to determine the most desirable web), and (e) steel yield point, with the capacity for using a higher strength steel for the skin plate than for the remainder of the leaf.

Structural design specifications used in the program are in accordance with EM 1110-1-2101. Items not covered by this EM are specified in accordance with the 1970 edition of AISC (Seventh Edition). The applicable allowable AISC stresses are reduced to 83% of the stresses shown in the AISC Specifications.

The computer program, when set up by a designer familiar with gate design, can, after one or two programs have been run, result in time savings of up to 50% of the normal time for manual computations. Other aspects of design are being considered for extensions to the present program; diagonal design is the most desirable at this time. Other items that may be needed are weights, center of gravity, and sectional properties of the entire leaf.

The printout of the program is such that it is easily understood and gives the actual sizes of all plates and members.

Lists of available programs

From the available information it appears that all programs that have been used for assistance in the design of miter gates are available through the Engineer Computer Programs Library, Technical Information Center, Waterways Experiment Station, Vicksburg, Mississippi. Only two

of these programs have been written directly for miter gates, the first being Miscellaneous Paper K-73-6, Computer-Aided Design of Horizontally Framed Miter Gates, by W. L. Boyt. The second and most recent program, Library No. 713-SA-K53C, was written by C. J. Granade, Jr., in the Mobile District. The Pittsburgh District has used a program known as P TRUSS, a time-sharing program, Library No. 713-G9-A105, in conjunction with the preliminary design of diagonal bracing for a spare set of sectionalized 110-ft lock miter gates. There was a limitation in the capacity of the program and the structure had to be approximated with an equivalent structure. Other Districts have used the general purpose structural design program STRUDL, but apparently only for preliminary investigation of miter gates.

Programs adaptable for Corps-wide use

Indications at this time are that the most readily adaptable program is the one developed by the Mobile District. This program gives slightly more capability than any others as well as an easily understood direct printout of the size of the component and the location. It contains a brief description of symbols and a written heading of the component. A Corps-wide design manual on miter gates is being written by the Mobile District. The computer program will give these five items: the load on the girder, intercostal spacing, skin plate, horizontal girder spacing, and the transition section. The transition section is an area which was modified. On a 100-ft-high miter gate a situation was encountered where the heavy upstream flange of the centerline section and the heavy downstream flange on the end diaphragm section would have to overlap. That hadn't been anticipated. Normally, there will be a transition section where there is a minimum size flange upstream and a minimum size flange downstream. The reason girder spacing wasn't put into the computer was that it was felt that every time the computer did the spacing it came up with odd girder spacing that had to be readjusted.

Desirable features for future expansion of this program, as stated earlier in this paper, are design of diagonals, weight of gate leaf, center of gravity, and properties of a section cut through the entire leaf (section cut by a horizontal plane).

A good computer program should be one in which the input and output can be readily understood by designers who are not completely familiar with the detailed aspects of program writing. The input should be such that only the normal information relating to gate design, such as pool elevations, yield point of steel, girder spacing, etc., will be involved in establishing the necessary input. Someone other than a person who has previously designed gates should be able to read and follow the output; it is recognized that the person would have to have some knowledge of miter gates and their terminology. The output should also give directly the desired loads and thicknesses or member sizes, keeping to a minimum the number of manual calculations necessary after the program has been run.

Stop Logs

Design philosophy

Stop logs, whether for unwatering navigational locks, powerhouse intakes, or similar uses, are basically designed under the same general criteria. Stop logs are not normally considered to be emergency closures. Therefore the basic stress used in the design can be $0.67F_y$ (yield strength of material), or 111% of the allowable stresses indicated in AISC Specifications, for flood or maximum loading.

There are two kinds of stop logs--the lock stop log and the spillway stop log. (A bulkhead is usually treated in a separate category.)

As a general rule, the spillway stop log is made up of two plate girders with a box-type section.

Where the lock stop log length is approximately 115 ft 0 in. for a 110-ft 0-in. lock, the usual procedure is to design the logs as a box truss, with a height in the range of 5 ft. These logs are designed only for a static loading and cannot be used as an emergency closure for flowing water.

Where the bottom log is interchangeable, the design loads are applied at the center of the top half of the bottom log. Where the

bottom log is not interchangeable the log above the bottom log will be designed for the load on the bottom half of the log immediately above the bottom log. The pickup points are located near the quarter points of the log to minimize deadweight bending stresses and deflections. Reaction rollers are used on the ends of the longer logs to reduce binding and friction. This allows a log to be lifted under a small differential head, thereby reducing the filling time for the closed off area when work is completed. Guide rollers are also used, at 90 deg to the reaction rollers, to minimize the possibility of logs hanging up during installation or removal.

Difference between Corps procedure and outside industry

The Corps of Engineers and other Government agencies are the main users of stop logs as discussed in this paper. Some use is made of smaller members that could be classified as stop logs by industry, but these are not in the same category as those studied here.

In the design of the truss-type logs, the analysis of the truss members is about the same for both Corps and outside industry. In general the Corps is more inclined to be conservative than other designers, as is indicated by the reduction of allowable stresses specified in AISC.

The role of computers in design

Computer programs can be more easily adapted to the design of stop logs than to some of the more complex items such as miter gates. There is similarity of truss design or single plate girder design between the Corps and outside industry. Therefore, more programs have been written that can be adapted to stop log design than are available for miter gates or other units that are used almost exclusively by the Corps or Government agencies.

Lists of available programs

The Pittsburgh District has used two programs obtained from the Rock Island District and one written in Pittsburgh. The Pittsburgh program is based on GFRAME, written by W. D. Martin of the Memphis District. Pittsburgh District numbers assigned to these programs are:

(a) 713H4350, (b) 713H4360, and (c) 713H4390. These programs, used in late 1973, are oriented toward general-type trusses and frames and are not specially tailored for stop logs. These programs provided refinement that would not have been practical manually and saved time.

The North Pacific Division has used a computer program as an aid in the design of powerhouse draft tube and intake stop logs and bulkheads fabricated of steel. The program used, W13G472, is a finite element analysis of stiffened plates.

The St. Louis District has made use of the computer in the design of bulkheads. While bulkheads are not quite the same as truss or plate girder stop logs, parts of these programs might be of some value as an aid in the design of stop logs. The three programs used were written in the St. Louis District and are: (a) GVSCAT1 - section properties of built-up members, (b) GSVCAT2 - check of 1969 AISC steel code criteria, and (c) GVSCAT3 - same as GVSCAT2 with less output. Two other general purpose stiffness programs were also used, GFRAME, available at WES, and STRESS, also available at WES and GE time-sharing.

Programs adaptable for Corps-wide use

At this time there are no programs written specifically for stop log design so there is no clear indication if one program has a definite advantage over a similar one. One program should be modified or written especially for truss-type lock stop logs and one for smaller logs made of plate girders (normally, two girders form one stop log). The desirable features of a computer program for either the truss or plate-girder-type stop log should be basically the same as that outlined for a miter gate program: simplicity, ease of operation, input essentially the same as that needed for manual calculations, and an output that is easily read by someone not wholly familiar with computer language. Again, it is desirable that the output should give directly the desired loads, thicknesses, or member sizes, thus minimizing the need for additional manual calculations.

Recommendations and Comments from Computer-Aided Design Conference

The consensus of opinion appears to be that it would be desirable to investigate the potential use of a program for the design of truss and plate-girder-type stop logs. If the economic benefit of this program (or programs) would be such that, when compared with development and maintenance costs, a program is justified, then it should be developed along with an EM that would be acceptable Corps-wide.

The recommended program for miter gates is the one developed by the Mobile District. This program gives slightly more capability than any other and gives an easily understood printout of component size and location. This program gives an actual size rather than analyzing a preselected member. Desirable features to be added to the program at some future time are design of diagonals, weight of leaf, center of gravity, and properties of a section cut through the entire leaf.

There appears to be universal agreement that a Central Computer Center is necessary for the distribution and maintenance of all Corps programs, but not for the development of programs. Programs should be written by the individual District most familiar with the particular design element under consideration. The programs should be developed in accordance with EM design manuals and with input from all related organizations and units within the Corps. The final program may be made a part of design manuals if a new EM is being written at the time of the program development.

Funds should be made available specifically for program development with each District or organizational unit funded on the basis of need and capability. One central pool for funds does not seem to be the solution, as the funds would not necessarily be used for the most desirable goals in a given time period.

Appendix A: Computer Program Abstract

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
Miter Gate Design	713-S8-K5300

PREPARING AGENCY
U. S. Army Engineer District, Mobile

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
C. Jackson Granade, Jr.			

A. PURPOSE OF PROGRAM
The purpose of program "Miter Gate Design" is to produce a structural design of the major elements of horizontally framed miter gates. The following items will be computed or designed: 1. girder loads, 2. skin plate, 3. intercostals, 4. girder sections at center line, end diaphragm, and transition, 5. intermediate web stiffeners. 6. thrust diaphragm and stiffeners, 7. tapered end section, and 8. end diaphragm and stiffeners.

B. PROGRAM SPECIFICATIONS
Programs were written in Fortran IV for the Univac 1108 and GE 400 computers. The object program requires approximately 16,000 36-bit words for execution on the Univac 1108 and approximately 24,000 words for execution on the GE 400.

C. METHODS
Structural design specifications utilized in the program are in accordance with EM 1110-1-2101 or for items not covered by this EM, with 1970 edition of the publication of structural steel for buildings by AISC. The applicable allowable AISC stresses are reduced to 83% of the stresses shown in the AISC specification. Design assumptions comply with EM 1110-2-2603, Lock Gates (being prepared by Mobile District). Method used to design miter gate components by computer involves taking a minimum size section and increasing it incrementally until it is acceptable. This technique is employed in design of each item in the program.

D. EQUIPMENT DETAILS
Univac 1004 to Univac 1108 - Card reader and printer

GE 225 to GE 400 - Card reader and printer

E. INPUT-OUTPUT
Input - punched cards

Output - printed

F. ADDITIONAL REMARKS
Program card deck may be obtained from ADP Center, Mobile District, COE. Additional information may be obtained from author or ADP Center, Mobile District, COE.

APPENDIX A: QUESTION AND ANSWER PERIOD

Some of the give-and-take during the conference is indicated in these questions and answers.

Question to Sell: You mentioned that trashracks should be designed for 10 to 20 ft of head in some conditions and for 5 ft in other conditions.

Sell: OK. The difference is that draft tube trashracks are designed for 5 ft of head because we won't have debris buildup.

Price: The January 1971 Journal of the ASCE Power Division carries the trashrack article written by Lloyd Sell.

O'Donnell: Lloyd, I didn't understand why you used a higher allowable stress for A36 steel than you did for A588 steel.

Sell: In normal "generating only" trashrack design, OCE requested that we use 22,000 psi. For pump-turbine trashracks, because of many unknowns such as the submerged jet (model tests indicate three to four times the average velocity), we went to A588 but used 18,000 psi in order to obtain the stiffness desired.

Gibson: For those of you that work on miter gates, please fill out this questionnaire and return to me in two or three weeks.

Sell: On catapulting, the Omaha, St. Louis, and Kansas City Districts are sponsoring catapult model tests going on now at WES. We have movies for later.

Question to O'Donnell: You mentioned several programs used in tainter gate design. Do these programs consider biaxial bending of skin plate by distortion energy, a theory directed by the EM?

O'Donnell: I haven't had a chance to look at these programs in detail. The Huntington program determines strut and girder sizes and comes up with the most economical design. It is a complete design program and usually has to be run just one time. It is called "The Design of Three-Girder Tainter Gates." This program has been used on several spillway tainter gate problems. It has been compared with the EM.

O'Donnell: Anyone here from New England Division? I'd like to find out about their tainter gate program.

Answer: I don't think we have any tainter gate programs. All we have is a general purpose program. Check with Carney Terzian.

Barton from St. Louis: I use the STRUDL program. STRUDL will actually

check the design according to the AISC code. It will check beams and columns but not skin plate. You check a few individual components.

O'Donnell: Were you aware of these other programs?

Barton: No. STRUDL works well. We also used the fastdraw system to model tainter gates and view from all angles. The program determines deflection of the bottom girder due to hydrostatic loads.

HEPD: For earthquake design, the hydrodynamic forces are applied using the Westergaard Theory.

Mr. X: Finite element analysis direct stiffness program can be adapted to skin plate designs.

Sell: In answer to the question on catapulting--the problem comes in watering up. By enlarging the slot at the top of the gate the risk is minimized.

Question: What is dividing line between wheel and roller gates?

Sell: On wide spans roller gate deflection cannot be tolerated.

Question: Mr. Gibson, are there any design programs for miter gate diagonals?

Gibson: Not as yet. Mobile plans to write one.

APPENDIX B: BIOGRAPHICAL SKETCHES OF AUTHORS

Keith O'Donnell is the Assistant Chief of the Structural Branch, Engineering Division, Civil Works Office, Chief of Engineers, in Washington, D. C. He earned his Bachelor of Science and Master of Science Degrees in Civil Engineering from Kansas State University, where he was a member of Phi Kappa Phi Honor Society. In addition to his present position, he worked in general civil engineering for 4 years, as a structural designer for 5 years, and, for 16 years, as a structural engineer for OCE. In this last position he developed design criteria for engineering manuals and guide specifications. He has also taught civil engineering courses part-time for several years. Mr. O'Donnell was registered as a professional engineer by Kansas in 1949 and has served on the U. S. Committee on Large Dams and as a Consultant Member for the U. S. - Japan Panel on Wind and Seismic Effects.

Wiliam D. Churchill is Chief of the Architectural and Structural Section, Technical Engineering Branch, of the Missouri River Division in Omaha, Nebraska. He is a graduate of the University of Minnesota and is registered as a structural engineer in Nebraska.

Lloyd E. Sell is a mechanical engineer in the Mechanical Power Systems Section, Design Branch, of the Omaha District, Omaha, Nebraska. He has also worked for the Bureau of Reclamation as a design engineer, and for the U. S. Air Force as a utilities engineer. He graduated in mechanical engineering from the University of Nebraska in 1962. In 1970 he was a panelist in the ASCE Memphis Conference on Pumped Storage, State of the Art. He authored ASCE Paper No. 7819, Hydroelectric Power Plant Trashrack Design.

James D. Gibson, Jr., the session chairman, is a structural engineer with the Mobile District in Mobile, Alabama. He graduated from Auburn University in 1956 with a B.S. in Building Construction from the School of Architecture. After a two-year active duty tour as a Commissioned Officer with the U. S. Army Corps of Engineers, he returned to civilian duty with the Corps, moving to MD in 1959. He was

registered as a Professional Engineer by Alabama in 1969, having been rated as a Structural Engineer by the Corps while on active duty. He has designed miter gates for several dams, and also done tainter valve, tainter gate, railway and highway bridge, electrical switchyard tower, aircraft hanger, and building design. Mr. Gibson helped develop the MD computer program, "Design of Horizontally Framed Miter Gates" and is presently developing for OCE a Design Manual for Lock Gates which will be compatible with the program.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Corps-Wide Conference on Computer-Aided Design in Structural Engineering, New Orleans, La., 1975.
[Proceedings ... held in New Orleans, Louisiana, 22-26 September 1975] Vicksburg, Miss., Automatic Data Processing Center, U. S. Army Engineer Waterways Experiment Station, 1976-
12 v. illus. 27 cm.
Contents.-v.1. Management report.-v.2. List of computer programs for CADSE.-v.3. Invited speeches and technical presentations.-v.4. Division presentations.-v.5. State-of-the-Corps-Art (SOCA) reports on gravity monoliths, U-frame locks, and channels.-v.6. SOCA reports on gates, stoplogs, and trashracks.-v.7. SOCA reports on single- and multiple-cell conduits and tunnels.-v.8. SOCA reports on pile foundations and sheet pile cells.-v.9. SOCA reports on sheet pile walls and T-walls.-v.10. SOCA reports on stiffness methods, frames, and military construction.-v.11. SOCA reports on earthquake and dynamic analyses.-v.12. Interactive graphics, SEARCH and CORPS systems.

(Continued on next card)

Corps-Wide Conference on Computer-Aided Design in Structural Engineering, New Orleans, La., 1975.
[Proceedings ...] 1976-
(Card 2)

1. Computer-aided design -- Congresses. 2. Design -- Congresses. 3. Structural engineering -- Congresses. I. U. S. Army. Corps of Engineers. II. U. S. Waterways Experiment Station, Vicksburg, Miss.
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